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Stock assessment for Silvergray Rockfish (*Sebastes brevispinis*) along the Pacific coast of Canada

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Silvergray Rockfish (SGR) along the Pacific coast of Canada has been assessed at the request of the DFO Groundfish Management Unit (GMU) with respect to its status relative to provisional reference points established by the DFO Sustainable Fisheries Framework (SFF) (DFO 2009). These reference points are the upper stock reference point (USR) of $0.8B_{MSY}$ and the Limit Reference Point (LRP) of $0.4B_{MSY}$. Current status and 10-year projection probabilities for the population are given with respect to the above DFO SSF reference points as well as the reference points of $0.2B_0$ and $0.4B_0$, the probability of an increase in population size and the probability of exceeding u_{MSY}, the equilibrium exploitation rate at MSY.

This stock was assessed as a single coastwide stock after consultation with an assigned Technical Working Group (TWG), which considered the similarity in biology and abundance trends among sub-areas as well as the nearly continuous distribution of catch and CPUE along the coast. The TWG agreed to assess SGR as a single coastwide stock, with the provision that the current management approach of distributing the catches into management units be maintained as a precautionary measure and that 3CD (west coast of Vancouver Island) would have the lowest TAC among the management units.

An annual catch-at-age model tuned to six fishery-independent survey series, annual estimates of commercial catch since 1940, nine years of age composition data from four survey series, and 25 years of age composition data from the commercial fishery provided the foundation of this advice. The model was started from an equilibrium state in 1940, and the survey data spanned the period 1967 to 2013. The two-sex model was implemented in a Bayesian framework (using the Markov Chain Monte Carlo procedure) with 26 estimated parameters in addition to the recruitment deviations. These parameters included natural mortality (M) for each sex and "steepness" (h) to determine the Beverton-Holt stock-recruitment function, which were both constrained by informative priors, as were the 15 selectivity function parameters.

Both model scenarios imply a slow-growing, low productivity stock that has undergone periods of high recruitment in the 1980s and recently in the early 2000s. The base case run estimated B_{2014}/B_0=0.56 (5–95% range: 0.41–0.70) and B_{2014}/B_{MSY}=2.04 (5–95% range: 1.22–3.00), indicating that the stock is in the "healthy zone" as defined by the DFO Sustainable Fisheries Framework. The 2013 exploitation rate u_{2013} (ratio of total commercial catch to vulnerable biomass) is estimated to be 0.044 (5–95% range: 0.030-0.068) compared to u_{MSY}=0.145 (5–95% range: 0.064-0.030).

Ten year projections, assuming random recruitment, provide probabilities of future population status with respect to the above reference points over a range of constant catch scenarios, applied without feedback controls.

Évaluation du stock de sébaste argenté (*Sebastes brevispinis*) le long de la côte du Pacifique du Canada

RÉSUMÉ

L'état du stock de sébaste argenté le long de la côte du Pacifique du Canada a été évalué à la demande de l'Unité de gestion des poissons de fond (UGPF) du MPO par rapport aux points de référence provisoires établis par le Cadre pour la pêche durable (CPD) du MPO (MPO 2009). Ces points de référence sont le point de référence supérieur du stock (PRS), de $0,8B_{rms}$, et le point de référence limite (PRL), de $0,4B_{rms}$. L'état actuel et les probabilités d'évolution de la population tirées de projections sur 10 ans sont donnés par rapport aux points de référence du CPD du MPO mentionnés ci-dessus ainsi qu'aux points de référence de $0,2B_0$ et $0,4B_0$, à la probabilité d'une augmentation de la taille de la population et à la probabilité de dépassement de u_{rms}, le taux d'exploitation d'équilibre en fonction du RMS.

Ce stock a été évalué comme un stock unique pour l'ensemble de la côte après consultation du groupe de travail technique (GTT) responsable, qui a tenu compte des similitudes des propriétés biologiques et des tendances relatives à l'abondance entre les sous-secteurs ainsi que de la répartition quasi continue des captures et de la CPUE le long de la côte. Le GTT a convenu d'évaluer le stock de sébaste argenté en tant que stock unique pour l'ensemble de la côte, à condition que l'approche de gestion actuelle consistant à répartir les prises en unités de gestion soit maintenue à titre préventif et que le TAC le plus faible parmi les unités de gestion soit attribué à la zone 3CD (côte ouest de l'île de Vancouver).

Les recommandations du présent avis sont basées sur un modèle annuel de prises selon l'âge ajusté à six séries de relevés indépendants de la pêche, les estimations annuelles des prises commerciales depuis 1940, des données sur la composition selon l'âge couvrant une période de neuf ans tirées de quatre séries de relevés et des données sur la composition selon l'âge de la pêche commerciale couvrant une période de 25 ans. Le modèle postule un état d'équilibre en 1940 et les données des relevés couvrent les années comprises entre 1967 et 2010. Le modèle des deux sexes a été élaboré à l'aide d'un cadre d'évaluation bayésien (selon la méthode de Monte-Carlo par chaîne de Markov) et comporte 26 paramètres estimés en plus des écarts de recrutement. Ces paramètres comprenaient la mortalité naturelle (M) pour chaque sexe et la « variation » (h) afin de déterminer la relation stock-recrutement de Beverton-Holt; ces deux paramètres ont été limités par l'utilisation de valeurs a priori, ainsi que l'ont été les 15 paramètres de sélectivité.

Les deux scénarios de modèles suggèrent un stock à la croissance lente et à la productivité faible, qui a traversé des périodes de recrutement élevé au début des années 1980 et 2000. Dans le scénario de base, les valeurs estimées étaient de B_{2014} / B_0=0,56 (5 à 95 % : 0,41-0,70) et B_{2014} / B_{RMS}=2,04 (5 à 95 % : 1,22-3,00), ce qui indique que le stock se situe dans la « zone saine », telle que définie par le Cadre pour la pêche durable du MPO. Le taux d'exploitation de 2013 U_{2013} (rapport entre le total des prises commerciales et la biomasse vulnérable) est estimé à 0,044 (5 % à 95 % : 0,030-0,068) comparativement à U_{RMS}=0,145 (5 % à 95 % : 0,064-0,030).

Les projections sur dix ans, en supposant un recrutement aléatoire, présentent les probabilités concernant l'état futur de la population par rapport aux points de référence mentionnés ci-dessus pour un éventail de scénarios de prises constantes appliqué sans contrôle rétroactif.

1. INTRODUCTION

Silvergray Rockfish (*Sebastes brevispinis*) (SGR) is an important commercial species in British Columbia (BC), often taken along with Pacific Ocean Perch (*S. alutus*), Canary Rockfish (*S. pinniger*) and Yellowtail Rockfish (*S. flavidus*), as well as Lingcod (*Ophiodon elongatus*). This species ranges from southern California to the Bering Sea and is reported in commercial groundfish landings from northern Washington to the Gulf of Alaska (Stanley & Kronlund 2000). It is primarily taken at depths between 100 and 400m. Silvergray Rockfish are an aggregating species and are observed as plumes on sounders, usually next to steep bottom topography. Silvergray Rockfish are rarely caught in large quantities by midwater trawl.

Silvergray Rockfish are livebearers with internal fertilisation. Insemination occurs from September to January, with a peak in October. Females release live young (parturition) from May to August, with a peak from June to July (Stanley & Kronlund 2000). Large females can produce over 1.5 million larvae, although fecundity estimates are based on egg counts prior to internal hatching and larval development (Hart 1973).

In BC, the areas with highest CPUE (and, by inference, population) occur in the northern section of Queen Charlotte Sound and into the southern section of Hecate Strait, apparently following the contours of Moresby and Mitchell's Gullies (Figure 1). There are also areas of apparent high density off the northwest and west coasts of Graham Island. This species also occurs along the west coast of Vancouver Island (WCVI) but its density appears to be lower in more southern latitudes. Ages greater than 70 are common in the DFO GFBio database, with the maximum recorded age being 82 years.

Silvergray Rockfish have a relatively large coastwide total allowable catch (TAC), currently set at an annual value of 1,433 t (Table A.1). The annual TAC is split between trawl (1267 t) and the hook and line sector (166 t) (IFMP 2013, p 42).

1.1. PURPOSE OF DOCUMENT

This document provides stock assessment advice to fisheries managers for Silvergray Rockfish. This advice was requested by the Groundfish Management Unit (GMU) of the DFO Pacific Region, which specified that the advice be framed in terms of the DFO Sustainable Fisheries Framework (SFF) (see *Fishery Decision-making Framework Incorporating the Precautionary Approach*, DFO 2009). This advice is presented as a set of decision tables that provide probabilities of exceeding reference points over a range of projection years and across a range of constant catch scenarios (without feedback controls). Reference points are defined below.

We used a modified version of the Coleraine statistical catch-at-age software (Hilborn *et al.* 2003), called Awatea, to complete this task (Appendix D). The model is an annual two-sex catch-at-age model tuned to: six fishery-independent trawl survey series, annual estimates of commercial catch since 1940, age composition data from the commercial fishery (25 years of data) and age composition data from four of the survey series (nine years of data). Growth parameters were estimated from Silvergray length and age data using research biological samples collected from 1978 to 2011. The model estimates steepness of the stock-recruitment function, natural mortality (independently for females and males), catchability coefficients for the survey series, and selectivity parameters for the commercial fishery and four of the six survey series for which age data are available. The model also estimates recruitment deviations by year from the stock-recruitment function.

The model reconstructs trajectories of spawning and vulnerable biomass, age and sex structure of the population, recruitment and exploitation rates. The suite of estimated parameters are

used to calculate derived parameters of management interest, including B_0 (the unfished equilibrium female spawning biomass associated with average recruitment), B_{MSY} (the equilibrium biomass associated with the maximum sustainable yield – MSY) and the status of biomass levels relative to these quantities and other reference points of interest. Projections are performed to estimate future probabilities of the spawning biomass being greater than the reference points under a range of constant catch scenarios.

1.2. RANGE AND DISTRIBUTION

The BC population of Silvergray Rockfish appears to be centred in the northern part of Queen Charlotte Sound (QCS, central BC coast), in association with the two of the three main gullies: Moresby and Mitchell's Gullies (Figure 1). There are also areas of high density off the northwest coast of Graham Island and in Rennell Sound off the west coast of Graham Island. Densities of Silvergray Rockfish are lower in Goo[illegible]sland Gully in southern QCS and around the northwest end of Vancouver Island. Densities become lower the further south one goes on the west coast of Vancouver Island. This species has been encountered by the BC trawl fleet over an estimated 48,000 km^2 (Figure 1), and 98% of the coastwide tows which captured Silvergray Rockfish lie between depths 82 m and 388 m.

1.3. ASSESSMENT BOUNDARIES

Silvergray Rockfish are divided into four management areas by the GMU of DFO for the purposes of setting a TAC: 3CD, 5AB, 5CD and 5E (Figure 2; Appendix A). Stanley & Kronlund (2000) provide a history of the stock advice for Silvergray Rockfish, noting that there was a tendency over time to combine management areas before reaching the present management unit definitions. Stanley & Kronlund (2000) note at the end of their discussion on stock boundaries that "*...We emphasise that there is little biological basis for any of the current stock boundaries. No genetics or tagging studies have been conducted on this species that might assist in the delineation of stocks boundaries.*" This advice was repeated in the follow-up stock assessment by Stanley & Olsen (2002).

The Silvergray Rockfish Technical Working Group (TWG) met in August 2013 to consider the issue of stock boundaries by reviewing available data on growth and abundance trends. Growth functions generated for 3CD, 5ABC and 5DE were all very similar as are the abundance trends among these same area combinations. There is a nearly continuous distribution of catch and CPUE along the coast (e.g., Figure 1; Appendix A). Given this information, the TWG decided that Silvergray Rockfish should be assessed as a single coastwide stock, with the provision that the existing management units would be retained with separate TACs and that 3CD would continue to have the smallest TAC. This pragmatic approach is consistent with similar decisions made for recent assessments of Canary Rockfish (Stanley et al 2009a), Bocaccio Rockfish (MacAllister et al. 2011), and Yellowmouth Rockfish (Edwards et al. 2012a).

2. CATCH DATA

The catch history and the methods used to prepare the catch data for this assessment are provided in Appendix A. Total catches peaked at 4,033 t in 1966 (during a period of intense fishing by foreign fleets) (Figure 3). There was another period of high catches in the mid- to late 1980s and again in 1994. Trawl catches dominate Silvergray Rockfish landings, accounting for 97% of all landings in the period from 1940 and 96% of the landings between 2008 and 2012. The recent coastwide five year (2008-2012) average catch has been 1408 t, which breaks down to 1,350 t by trawl, 56 t by hook & line and less than 2 t by the sablefish fishery.

3. FISHERIES MANAGEMENT

Appendix A summarises management actions that potentially affect Silvergray Rockfish in Canadian waters since 1979. The appendix also contains a history of Silvergray Rockfish TACs that likely remains incomplete for earlier years.

4. SURVEY DESCRIPTIONS

Six independent surveys were used to describe Silvergray Rockfish abundance in the stock assessment model (details in Appendix B, including justification for inclusion or exclusion of surveys). These surveys cover a period from 1967 to 2013. The six surveys are:

1. an early series of seven indices extending from 1967 to 1984 operating in the Goose Island Gully in the southern part of QCS. These surveys were performed by the research vessel GB Reed up to 1984, with the commercial fishing vessel Eastward Ho added in 1984. A comparison of the observed 1984 catch rates from the GB Reed and Eastward Ho showed no significant difference, allowing for the combining of the 1984 tows from the two vessels. Two other surveys operating in this area were considered by the TWG: a 1994 Ocean Selector survey which used the same design as the pre-1994 surveys and a random design survey conducted by the Ocean Selector and the Frosti. These two surveys were not used in the base case Silvergray Rockfish data set because (a) the timing of the 1994 survey differed by two months from earlier surveys and (b) the 1995 survey design was considerably different from the earlier surveys, including its optimization for Pacific Ocean Perch. This survey series is referred to as the "GIG historical" survey series.
2. a transect-design trawl survey covering the lower half of Vancouver Island and most of the Washington State coast south of Juan de Fuca Strait. This survey was operated by the US National Marine Fisheries Service (NMFS), and was repeated seven times using 11 vessels over the period 1980 to 2001. This survey is referred to as the "US Triennial" survey series.
3. a random-stratified "synoptic" trawl survey covering the west coast of Vancouver Island (WCVI). This survey has been repeated five times between 2004 to 2012 using the same vessel and a consistent design, including targeting a wide range of finfish species. The series is referred to as the "WCVI synoptic" survey series.
4. a random-stratified "synoptic" trawl survey covering all of Queen Charlotte Sound (QCS). This survey has been repeated seven times between 2003 to 2013 using three vessels and a consistent design, including targeting a wide range of finfish species. This series is referred to as the "QCS synoptic" series.
5. a random-stratified "synoptic" trawl survey covering all of Hecate Strait (HS) and extending into Dixon Entrance and across the top of Graham Island. This survey has been repeated five times between 2005 to 2013 using two vessels and a consistent design, including targeting a wide range of finfish species. This series is referred to as the "HS synoptic" series.
6. a random-stratified "synoptic" trawl survey covering the west coast of Graham Island in Haida Gwaii (HG) and western part of Dixon Entrance. This survey has been repeated five times between 2006 to 2012 using three vessels and a consistent design, including targeting a wide range of finfish species. This series is referred to as the "WCHG synoptic" series.

These relative biomass survey series were used as input data to the stock assessment model along with the associated relative error for each index value.

5. BIOLOGICAL INFORMATION

5.1. BIOLOGICAL SAMPLES

Commercial catches of rockfish by trawl gear have been sampled for age proportions since the 1960s. However, only Silvergray Rockfish otoliths aged using the "break and burn" method have been included in the age samples used in this assessment because the earlier surface ageing method is known to be biased, especially with increasing age. Practically, this means that no age data were available before 1978. Commercial fishery age samples were summarised by trip for each quarter, weighted by the Silvergray Rockfish catch weight for the sampled trip. The quarterly samples were scaled by the quarterly landed commercial catch weights to give annual proportions-at-age data (details are in Appendix C).

Age samples were available from four of the above synoptic surveys (WCVI synoptic, QCS synoptic, HS synoptic and WCHG synoptic). These samples were scaled to represent the total survey in a manner similar to that used for the commercial samples: within a depth/area stratum, samples were weighted by the Silvergray Rockfish catch density in the sampled tow; stratum samples were then weighted by the total area of the stratum (described in Appendix C).

5.2. GROWTH PARAMETERS

Growth parameters for both sexes were estimated from Silvergray Rockfish length and age data from biological samples collected from 1978 to 2011 by research surveys (Appendix C), with sex-specific growth estimated as a three-parameter von Bertalanffy model. Parameters for allometric weight-length relationships by sex were estimated for Silvergray Rockfish using commercial and research survey data. These two parameters allow determination of weights-at-age within the model, which are used to convert population numbers to biomass. These parameters are used in the model without any uncertainty component.

5.3. MATURITY AND FECUNDITY

Stanley & Kronlund (2000) presented a steep maturity curve based on the assumption that all stage 2+ female Silvergray Rockfish were mature (Figure 4), where stage of maturity was determined macroscopically and samples were placed into one of seven maturity stages, progressing from 1 (least mature) to 7 (spent) (Stanley & Kronlund 2000). An alternative maturity function was presented in a later paper (Stanley & Kronlund 2005), which was based on the assumption that female Silvergray Rockfish in stages 1 and 2 were immature and the remaining stages were mature (Figure 4). We investigated both of these assumptions, using age and maturity data up to 2011 (which was the last year of available ageing data) and confining the maturity observations to the months of April–July (after discussion with the TWG) using commercial and research survey data. A function (Eq. C.3) was fit to the resulting female proportions at age to estimate an ascending vector of proportion mature m_a. Figure 4 shows that the maturity ogive based on the Stage 2+ assumption is knife edged between ages 7 and 8 while the Stage 3+ assumption gives a maturity ogive that is more gradual, with an age at 50% maturity near age 10 and an asymptote of 1.0 after age 15 (see Figure 4). Figure 4 also shows that the maturity ogive based on the Stage 2+ assumption is steeper than, but has a similar age at 50% maturity to, the ogive estimated by Stanley & Kronlund (2000) and that the Stage 3+ ogive is very similar to the published ogive from Stanley & Kronlund (2005). Consequently, we used the Stage 3+ ogive as input to the base case Silvergray Rockfish stock assessment model

and the Stage 2+ ogive was used for a sensitivity run. We substituted the values for ages 3 to 6 from the Stanley & Kronlund (2005) ogive due to missing values in the available data to fit our model (see Table C.3).

Fecundity was assumed to be proportional to female body weight.

5.4. NATURAL MORTALITY

Male and female natural mortalities M_s were estimated as parameters of the model (see Appendix D). This was done using a strong informed prior with a mean of 0.06 and a standard deviation of 0.006 (CV=10%) (Table 1A) for both sexes. The mean value was taken from Stanley & Kronlund (2000), who state that M=0.06 is the "*...best estimate for M for Silvergray Rockfish*". We adopted a CV=10% to ensure that the estimated value remained near to the "best estimate" and was similar to priors for *M* used for Pacific Ocean Perch (POP) (Edwards et al. 2012b, Edwards et al. 2014a, Edwards et al. 2014b) and Yellowmouth Rockfish (Edwards et al 2012a).

5.5. STEEPNESS

A Beverton-Holt (BH) stock-recruitment function was used to generate average recruitment estimates in each year, based on the biomass of spawning females (Equation D.10). Recruitment deviations from this average (Equations D.17 and D.24) are estimated to improve the fit to the model data. The BH function was parameterised using a "steepness" parameter, *h*, which specified the proportion of the maximum recruitment that was available at 0.2 B_0, where B_0 is the female virgin spawning biomass. The parameter *h* was estimated in the model, constrained by a prior developed for west coast rockfish by Forrest *et al.* (2010). This prior took the form of a beta distribution with mean 0.674 and standard deviation 0.168 (equivalent to the beta distribution parameters: alpha=4.574, beta=2.212; Table 1A).

5.6. SELECTIVITIES

Early model fits using uniform priors for estimating the survey and commercial selectivity parameters showed very poor residual patterns for the fits to the survey age composition data. To remedy this, a set of informed priors for the survey selectivities were developed to constrain the estimated selectivity parameters into regions where the fits to the age data seemed more satisfactory (Table 1B). These priors were taken from the POP selectivity posterior distributions estimated using the same model structure: POP is a rockfish of similar size to Silvergray Rockfish taken in the same surveys. Table 1B provides the priors and fixed values used for the six Silvergray Rockfish survey selectivities. The three commercial selectivity parameters were estimated using uninformative priors.

Three parameters were required for each selectivity function: (a) the mode of the female selectivity function, (b) the variance of the left-hand side of the female selectivity function and (c) a parameter which "shifts" the selectivity mode to represent males. A fourth parameter, the right-hand variance, was fixed at the maximum selectivity (1.0) to ensure that the selectivity curve did not become dome-shaped which could introduce cryptic biomass within the model. The prior mean for each survey selectivity parameter was based on the posterior median from the specified POP base case parameter set, which was assumed to be normal with a 30% CV (Table 1B). Estimated parameters used the prior mean as the starting value and the selectivity parameters which were not estimated used the prior mean as the fixed value (Table 1B).

5.7. DATA WEIGHTING

The relative weights assigned to the different data components represent an important issue to address in statistical catch-at-age models. Francis (2011) has noted that adjacent age and length composition observations are usually correlated but that most likelihood functions (such as multinomial or lognormal) treat each observation as independent. This treatment over-weights the composition data relative to the other fitted data. Statistical catch-at-age models usually have a large number of age (or length) composition observations, which tend to overwhelm other sources of information, particularly abundance information where there are often only one or two observations per year.

Francis (2011) recommended two steps to deal with this problem: 1) add process error to abundance indices, and 2) downweight the age composition data to minimise the effect of the correlation structure. Francis (2011) suggested adding 0.2 to the CV from each observation, but acknowledges that some surveys might need to have more process error added. We chose to add different levels of process error to the six series of survey data used in this model, selecting the value of the process error which would bring the standard deviation of the normalised (Pearson) residuals of the fit to the survey indices to be near 1.0[1]. However, the added process error was not allowed to exceed 0.4 so that the associated survey indices were not entirely devalued. The age composition data were iteratively refitted using the Francis (2011) procedure TA1.8 (described in Appendix D).

6. AGE-STRUCTURED MODEL

A two-sex, age-structured stochastic model was used to reconstruct the population trajectory of coastwide Silvergray Rockfish from 1940 to the beginning of 2014. Ages were tracked from 1 to 32, with 32 being an accumulator age class. The initial population was assumed to be in equilibrium with average recruitment with no fishing at the beginning of 1940. Selectivities by sex for four of the surveys and the commercial fishery were estimated using a four parameter double "normal" (half-Gaussian) function (see selectivities section above). The model equations and implementation are described in Appendix D.

The base case model was fit to the available data (six sets of survey indices, 25 years of proportions-at-age from the commercial fishery and nine years of proportions-at-age from four of the six surveys) by minimising a function that summed the negative log-likelihoods arising from fit of the model predictions to each data set, the deviations from mean recruitment and the penalties from the Bayesian priors. The base case run excluded the 1994 and 1995 survey indices from the GB Reed Historical Survey series for reasons given above, but these indices were included in an MPD sensitivity run (Table F.*1*).

The minimised MPD (mode of the posterior distribution) "best fit" was used as the starting point for a Bayesian search across the joint posterior distributions of the parameters using the Monte Carlo Markov Chain (MCMC) procedure. The MCMC chain length was 10,000,000, with a sample taken every 10,000 to give a posterior of 1,000 samples. The entire chain was used for the posterior, without requiring a "burn-in" period. No burn-in was required because the MCMC searches started from the MPD values, with sequences not expected to move substantially from

[1] 1.0 would be the expected standard deviation of a standard normal curve with mean=0. A standard normal distribution of normalised residuals should be the result if the model is using the correct distribution for the fitted data.

initial values and the chains were very long and sparsely sampled. These samples were used to estimate parameters and quantities of interest, including stock status by year and the probabilities of being above reference points.

Initial model fits to the data gave sensible and consistent results once suitable priors for the survey selectivities were implemented. The range of potential sensitivity runs was limited, although five are presented here:

S1: an MCMC run which fixed M=0.06 for both sexes;

S2: an MCMC run which used the alternative steep Stage 2+ maturity ogive;

S3: an MCMC run which used uniform priors for the estimated selectivities instead of the informed priors based on the earlier POP assessments;

S4: an MPD run which restored the 1994 and 1995 GB Reed Historical survey series indices;

S5: an MPD run which imposed a fixed process error of 0.2 (as recommended by Francis 2011) for each survey index series rather than the variable process errors used in the base case run.

7. MODEL RESULTS

The MPD fits to the data were acceptable, particularly the fits to the commercial age composition data, which were exceptionally good (see Appendix E: Figures E.2, E.3 and E.14). There were some poor fits to some survey index points, such as the 2013 index from the QCS synoptic survey, which was much higher than could be fit by the model (see Figure E.1). The fits to the survey age composition data were not as good as those to the commercial age data, perhaps reflecting the multi-species nature of these surveys and a sampling design that cannot target any single species for optimal biological sampling (see Figures E.4 to E.7 and E.15 to E.18). Francis (2011) recommended using a diagnostic plot that compare the observed and predicted mean age (or length) by year to see if the model has captured that dynamic. Figure E.19 shows that the base case model fits the commercial annual mean ages very well while the survey mean ages are too sparse to make a strong case either way.

Catch levels were relatively low throughout the exploitation history for this stock (Figure 5). Nevertheless, the stock size was reduced by just over one-half by the early 1990s, followed by a long period of little change, although there is a suggestion that stock sizes may be increasing in the most recent few years (Figure 6). The reason for the gradual decline in biomass up to the end of the 1980s can be seen in the recruitment plot, which shows only two episodes of good recruitment: one in the first half of the 1980s and the second in 2000 and 2001 (Figure 7). The first period of good recruitment persisted for about 3-4 years and was probably responsible for the levelling out of the biomass trajectory when these recruits reached the fishery. It is possible that each recruitment episode was only from a single year class, with the attribution of recruitment strength to adjacent year classes due to ageing error (Rick Stanley, pers. comm.). If ageing error were modelled, the total recruitment attributed to these episodes should be the same as for this model; however, the present model will underestimate the extent of recruitment variation because the total recruitment is divided among several year classes. The second period of good recruitment, while only for one or two years, is probably responsible for the apparent recent upturn in predicted biomass, combined with current low exploitation rates.

The trajectory of annual exploitation rates shows a gradual increase from 0.06 to about 0.1 for the decade between 1985 and 1995 (Figure 8). Exploitation rates abruptly dropped in 1996 to below 0.05 and have since remained at that level (Figure 8). This also is the level that was reached in 1966 when catch peaked at 4,033 t at the beginning of the fishing down phase. To put these exploitation rates in the context of B_{MSY} and u_{MSY}, a phase plot which relates the

biomass and exploitation rates relative to these quantities shows that the biomass was never less than twice B_{MSY} and rarely above one-half of u_{MSY} (Figure 9).

Five sensitivity runs were made, three of which were evaluated by an MCMC search across the parameter space. None of these sensitivities departed far from the results of the base case (see Appendix F). Figure 10 demonstrates, for the three sensitivity runs evaluated by MCMC, that there is little difference between these runs in terms of performance relative to B_{MSY}. The largest difference relative to the base case among the five sensitivity runs occurs in S3, which used non-informative priors for estimating the survey selectivity parameters (Figure 10, Figure F.*1*, Figure F.*2*) and in S4, which included the 1994 and 1995 historic Goose Island Gully survey estimates (Figure F.*4*, Figure F.*5*). However, both these sensitivity runs still estimate that stock status is above 50% B_0 (S3: posterior median B_{2014}/B_0=0.54 (5–95% range=0.38-0.67) (Table F.2); S4: MPD B_{2014}/B_0=0.53 (Table F.*3*)

8. ADVICE FOR MANAGERS

8.1. CURRENT STOCK LEVEL

The estimated beginning year 2014 stock status (2014 spawning biomass relative to B_0) is 0.559 (5–95% range=0.405-0.698) for the base case. The estimated ratio of spawning biomass at the start of 2014 to the equilibrium spawning biomass associated with MSY, B_{2014}/B_{MSY}, is 2.035 (5–95% range=1.223-2.997) (Table 2). The estimated median MSY is 1,998 t (5-95% range=1,299–2,688) (Table 3). For reference, the average catch from 2008-2012 is 1,408 t.

8.2. REFERENCE POINTS AND CRITERIA

Decision tables are presented (in Appendix E, with a subset of these tables in Table 4 and Table 5) with respect to two sets of reference points: one set based on B_{MSY} (the equilibrium spawning biomass of mature females that will support the maximum sustainable yield, MSY) and the other based on B_0 (the equilibrium spawning biomass associated with average recruitment). Decision tables are also presented which evaluate the probability of exceeding u_{MSY}, the equilibrium mid-season exploitation rate associated with B_{MSY}, and the probability of the stock in B_{2024} increasing relative to B_{2014}. All reference points and criteria and the associated probabilities were derived from the posterior distributions of the Bayesian output from the model.

The Sustainable Fisheries Framework (SFF) (DFO 2009) established provisional reference points to guide management and assess harvest in relation to sustainability. These reference points are the upper stock reference point (USR) of $0.8B_{MSY}$ and the limit reference point (LRP) of $0.4B_{MSY}$, which are reported by request from the GMU for providing advice that is consistent with the SSF DFO policy. In the context of the SFF (DFO 2009), the zone below the limit reference point ($0.4B_{MSY}$) is termed the "critical zone" while the zone lying between the two reference points is termed the "cautious zone". The region above the upper stock reference point ($0.8B_{MSY}$) is termed the "healthy zone". B_{MSY} is also reported here as an additional reference point.

Figure 6 shows that the Silvergray Rockfish coastwide stock is estimated to have been in the healthy zone for the entire historical period, even when taking into account the uncertainty included in this stock assessment run. Figure 10 shows the stock status at the beginning of 2014 relative to B_{MSY}: current stock status is estimated to be in the healthy zone and well above B_{MSY}.

The SSF stipulates that, when in the healthy zone, the fishing mortality must be at or below that associated with MSY under equilibrium conditions (u_{MSY}), ramped down when in the cautious

zone, and set to zero when in the critical zone. As described above, Figure 9 shows that biomass levels are presently estimated to be in the healthy zone, a state which is estimated to have existed since the start of fishing and has median fishing mortality well below the median u_{MSY} exploitation rate.

Other jurisdictions often use 'proxy' reference points that are expressed in terms of B_0 rather than B_{MSY} (e.g. New Zealand Ministry of Fisheries 2011), because B_{MSY} is often poorly estimated as it depends on estimated parameters and a consistent fishery although B_0 shares many of these same problems). Therefore, the reference points of $0.2B_0$ and $0.4B_0$ are also presented here. These are default values used in New Zealand respectively as a 'soft limit', below which management action needs to be taken, and a 'target' biomass for low productivity stocks, a mean around which the biomass is expected to vary.

Decision tables have also been prepared which show the probability of the stock increasing relative to the spawning biomass at the beginning of 2014, the last year of the stock reconstruction.

8.3. PROJECTION RESULTS AND DECISION TABLES

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions without feedback controls. The projections, starting with the biomass at the beginning of 2014, were made over a range of constant catch strategies (0-3,000 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix D for a description of this procedure).

The decision tables (Table 4: 5-year projections; Table 5: 10-year projections) indicate that the stock is expected to decline at catch levels greater than about 1,500 t/year. However, because the current median stock size is estimated to be above 50% of B_0, all investigated catch levels are expected to result in biomass levels that remain above the sustainability (relative to B_{MSY} or B_0) reference points over the next 10 years (to 2024). The decision table relative to the `NZ target' biomass level of $0.4B_0$ shows that the expectation would be that this stock would reach that 'target' in about 10 years at the highest catch level investigated (3000 t/year).

We caution that, although uncertainty is built into the assessment and its projections by taking a Bayesian approach for parameter estimation, these results depend heavily on the model, informative priors, and data assumptions (particularly the average recruitment assumptions) used for the projections. This latter problem lessens with the short-term 5 and 10 year predictions for long-lived stocks that recruit at older ages to the fishery, which is the case for Silvergray Rockfish because most of the recruitments in the projections are based on recruitments estimated during the stock reconstruction phase of the assessment.

9. GENERAL COMMENTS

This assessment depicts a slow-growing, low productivity stock that has undergone periods of high recruitment in the early 1980s and the early 2000s. This evaluation is similar to recent assessments of *Sebastes* species (e.g., 3CD, 5ABC and 5DE POP – Edwards et al. 2014b, Edwards et al. 2012b, Edwards et al. 2014a, respectively; Yellowmouth Rockfish - Edwards et al. 2012a; Canary Rockfish – Stanley et al 2009b; Bocaccio Rockfish – MacAllister et al. 2012). These assessments have shown that, while exploitation rates are low, productivity is also low and recruitment is episodic; unpredictable and recruitment events are often separated by decades. These characteristics make *Sebastes* species difficult to monitor (because biomass

shifts are decadal, not annual) and there is a constant need to keep exploitation levels well below the apparent abundance.

While this is a coastwide assessment, which implies that catches could be taken anywhere on the coast, the SGR TWG has recommended that it would be preferable to maintain the current management approach of distributing the catches into management units as a precautionary measure. The TWG also recommended that the 3CD management unit (WCVI) should have the lowest TAC among these management units in recognition that relative abundances appear to be lower in the more southern latitudes.

Although these *Sebastes* stocks are characterised as long-lived and slow-growing, several of these populations have shown the capacity to make a rapid recovery from biomass levels $<0.5B_0$ because large episodic recruitments can rebuild these stock to high levels. This has been demonstrated in the assessments for Yellowmouth Rockfish (Edwards et al. 2012a) and 5ABC POP (Edwards et al. 2012b) and may be happening at present for Silvergray Rockfish.

The five sensitivity runs that form part of this assessment demonstrate little difference in model results relative to the base case. We investigated the effects of changing the maturity ogive (run S2), fixing M (run S1), making another set of process error assumptions (run S5), and estimating the survey selectivity parameters with non-informed priors rather than the informative priors used in the base case (run S3). None of these investigations changed the overall conclusion that current stock size was between 0.5 and $0.6B_0$, indicating that the data appear to be key determinants of these results. In support of this conclusion, the remaining sensitivity run, run S4, which changed the data by restoring the low 1994 and 1995 survey indices, still concluded that the best estimate of stock size was $0.53B_0$. This sensitivity run was the least optimistic among the five sensitivity runs investigated (see Appendix F).

The results of this assessment are uncertain. Although this stock is relatively data-rich in recent years, the amount of historical data available to support the interpretation of the long catch history is relatively small, particularly for the early years of stock reconstruction. There are no biomass indices prior to the 1967 and the available age composition data are all relatively recent. Fortunately, the earliest age data provide some information on year class strengths into the 1960s (at least), due to the long-lived nature of the species and the apparent precision of the ageing methodology. Species identification in the commercial trawl fishery before 1991 was not rigorously followed, with POP being the only rockfish routinely identified at the species level. Even fish identified as POP may have actually been other rockfish such as Silvergray Rockfish.

It is acknowledged that there will be error in the ageing of Silvergray Rockfish but this aspect of the stock assessment was not pursued.

The parameter h (steepness) is difficult to estimate in these models because there is little information available in the data to estimate the parameter. This is particularly true here because of the restricted range of estimated spawning populations (see Figure E.20), with no observations at low stock abundance. However, the h parameter has considerable influence in determining important derived parameters such as B_0 and especially B_{MSY} (Punt et al. 2013), resulting in a strong reliance on the Forrest et al. (2010) prior. There is some updating of the h posterior relative to the prior at low values (see Figure E.34), but this effect is relatively small, with the posterior mean rising to 0.74 from the prior mean of 0.67. The prior supplied by Forrest et al. (2010) is a weighted distribution across a range of *Sebastes* stock assessments and thus represents the best available information for this parameter for coastwide Silvergray Rockfish. We did not conduct a sensitivity run to investigate h further because we had no basis on which to hypothesize an alternative. Such a sensitivity run would likely demonstrate that model results are sensitive to alternative priors for this parameter, but would not help us to provide advice

because an alternative prior would not represent the "best available information" required by the Sustainable Fisheries Framework.

Table 4 (5-year projections) and Table 5 (10 year projection) provide guidance to the selection of short-term management actions evaluated against a range of reference levels using a range of fixed catch strategies. These tables give estimates of the probabilities of possible outcomes at fixed levels of annual catch. The accuracy of these projections depends on the model being "correct", which includes all underlying assumptions. Although we explicitly include uncertainty in the parameter estimation procedure through using a Bayesian approach, this uncertainty only applies to the specified model and the weights which were assigned to the various data components. Projection accuracy also depends on future recruitment values and the assumed lack of management intervention in the constant catch scenarios.

10.FUTURE RESEARCH AND DATA REQUIREMENTS

The following issues should be considered when planning future stock assessments and management evaluations for Silvergray Rockfish:

1. Continue the suite of fishery-independent trawl surveys that are established across the BC coast. This includes obtaining age and length composition samples, allowing the estimation of survey-specific selectivity ogives.
2. Sampling for age structures should be enhanced in both the commercial fishery and the synoptic surveys. We note that there has been a reduction in the number of otoliths and samples since around 2005 (see Figure C.5 and Table C.5).
3. It may be possible to construct informed priors for survey catchability parameters that can be used in Bayesian models like the catch-age model presented here. Such priors could be developed by placing meaningful bounds on survey catchability, which in turn would help scale the biomass levels in the assessment.
4. Given the dependence of these models on the Forrest et al. (2010) prior for the steepness (h) parameter, this prior should be updated with the additional *Sebastes* spp. stock assessments completed since that analysis as well as investigating possible alternative approaches to this problem.
5. The Sclerochronology Laboratory at the Pacific Biological Station currently records uncertainty for each aged otolith. Research into the quantification of such uncertainty would allow ageing error to be better incorporated into models as used in this assessment.
6. Effort could be directed to studying how single populations, such as Silvergray Rockfish, are part of a complex system consisting of biological, ecological, and economic components. Such systems can have multiple stable states, which may have implications in our understanding of Silvergray Rockfish population dynamics and resilience.

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13.FIGURES

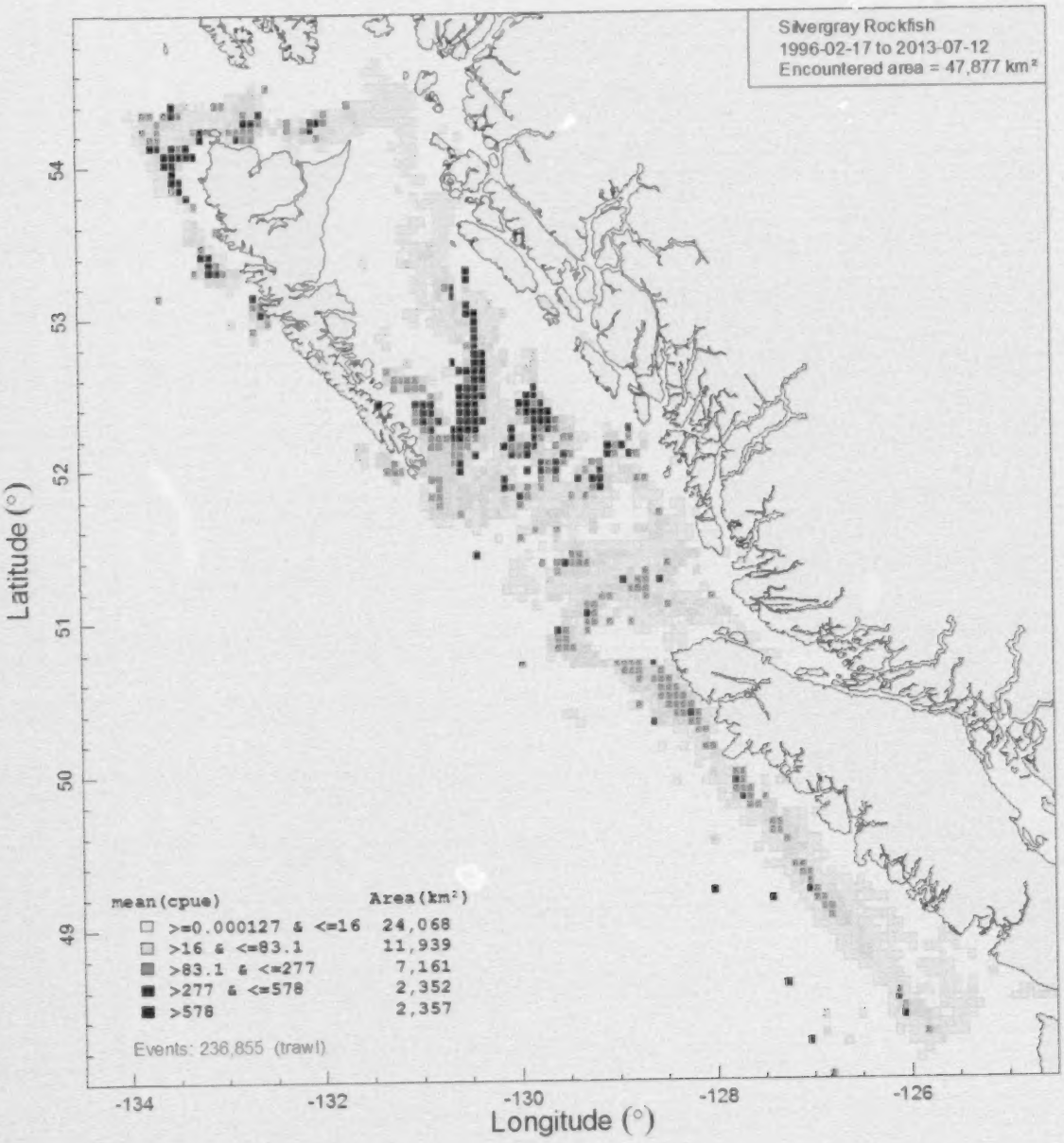

Figure 1. Mean CPUE (kg/h) of Silvergray Rockfish in grid cells 0.075° longitude by 0.055° latitude (roughly 32 km²). The shaded cells give an approximation of the area where Silvergray Rockfish were encountered by fishing events from the groundfish trawl fishery from February 1996 to July 2013.

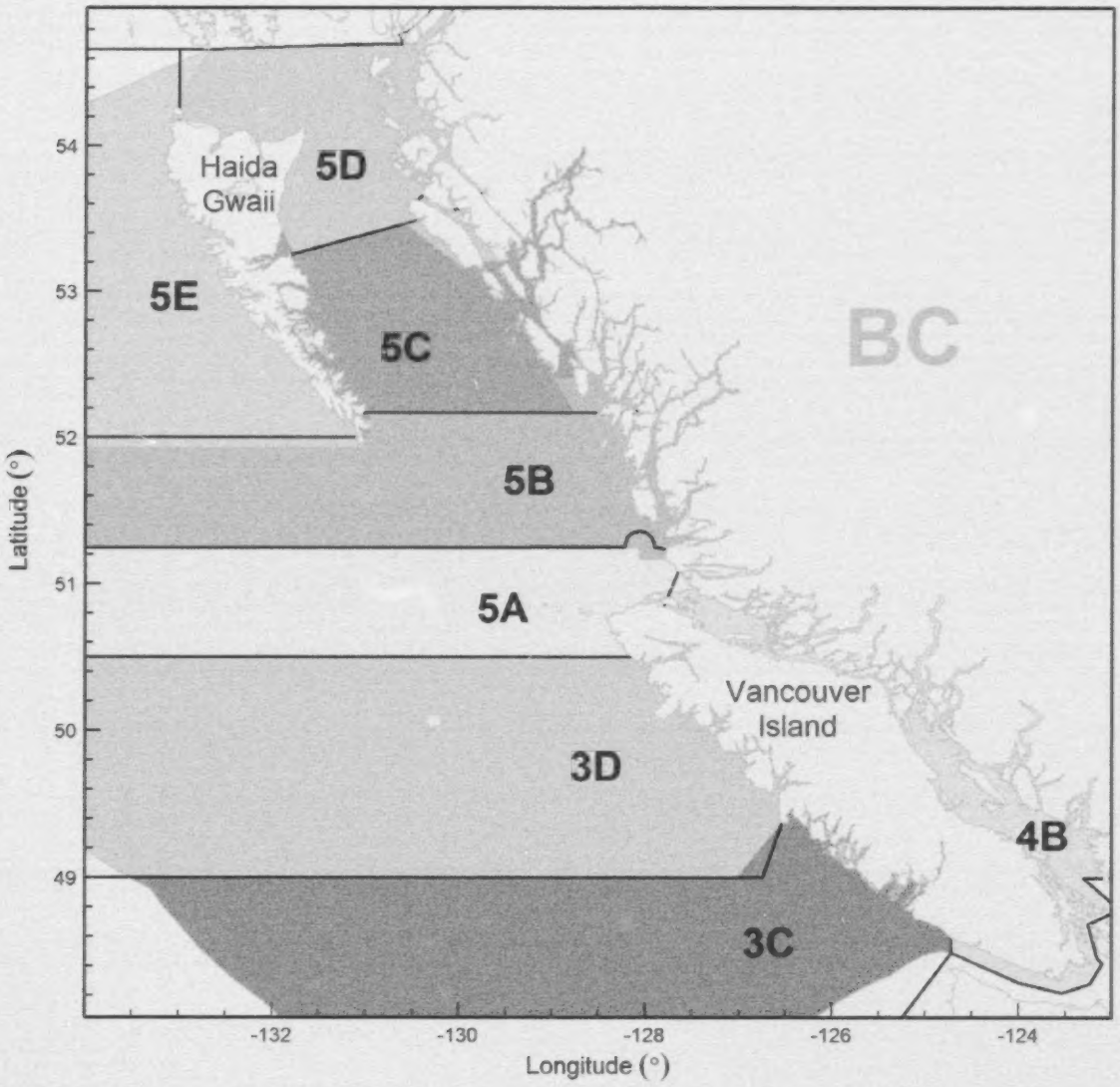

Figure 2. Pacific Marine Fisheries Commission major areas (outlined in purple) compared with Groundfish Management Unit areas for Silvergray Rockfish (shaded).

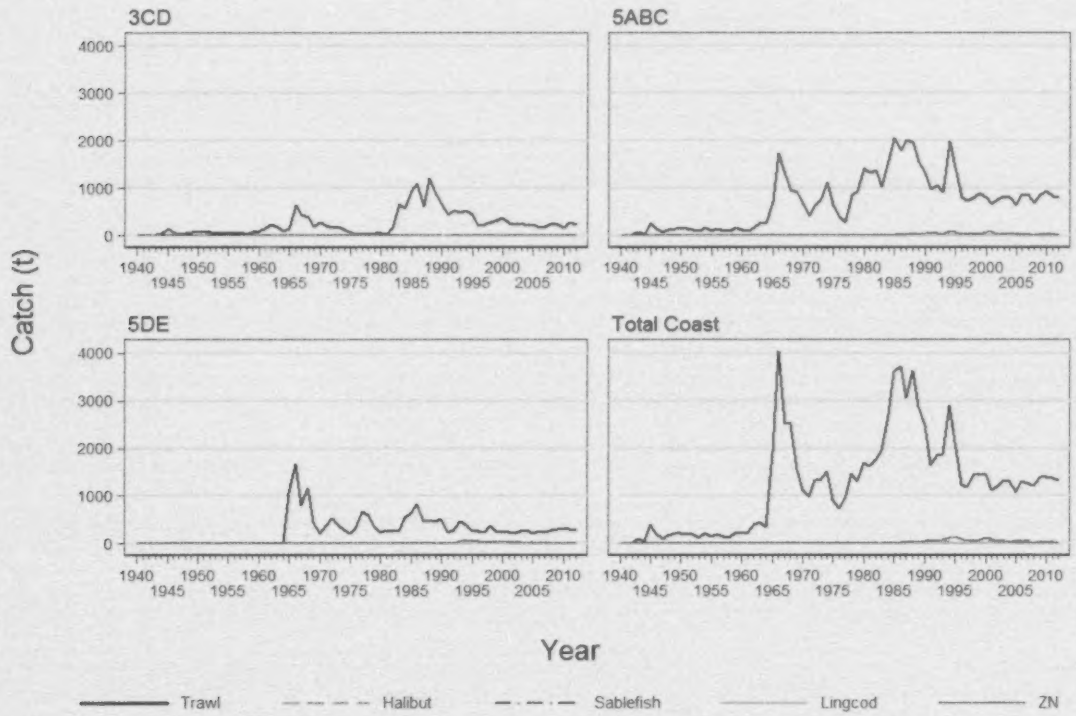

Figure 3. Catch (t) of Silvergray Rockfish by the indicated combined PMFC areas (see Figure 2) and for all the BC coast by license holder category. The "Total Coast" catch (including research survey catches, not shown) trajectory was used as input to the Silvergray Rockfish stock assessment model.

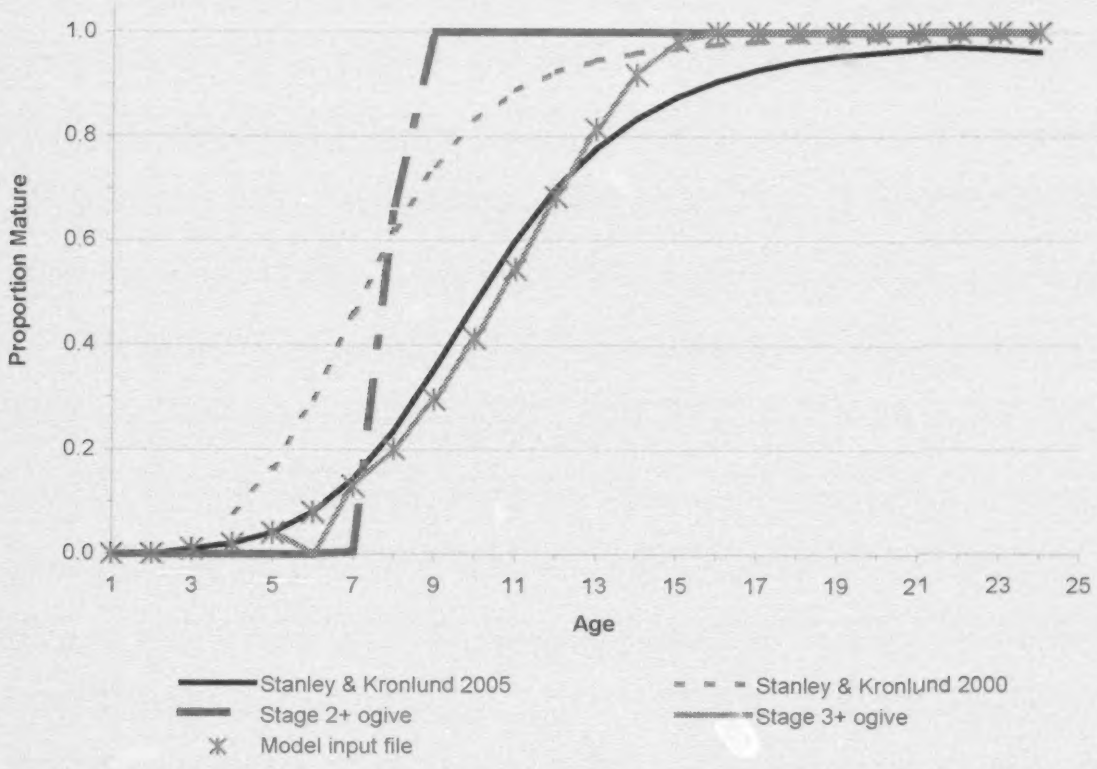

Figure 4. Five alternative maturity functions for Silvergray Rockfish. See text and Appendix C for a discussion of these alternatives.

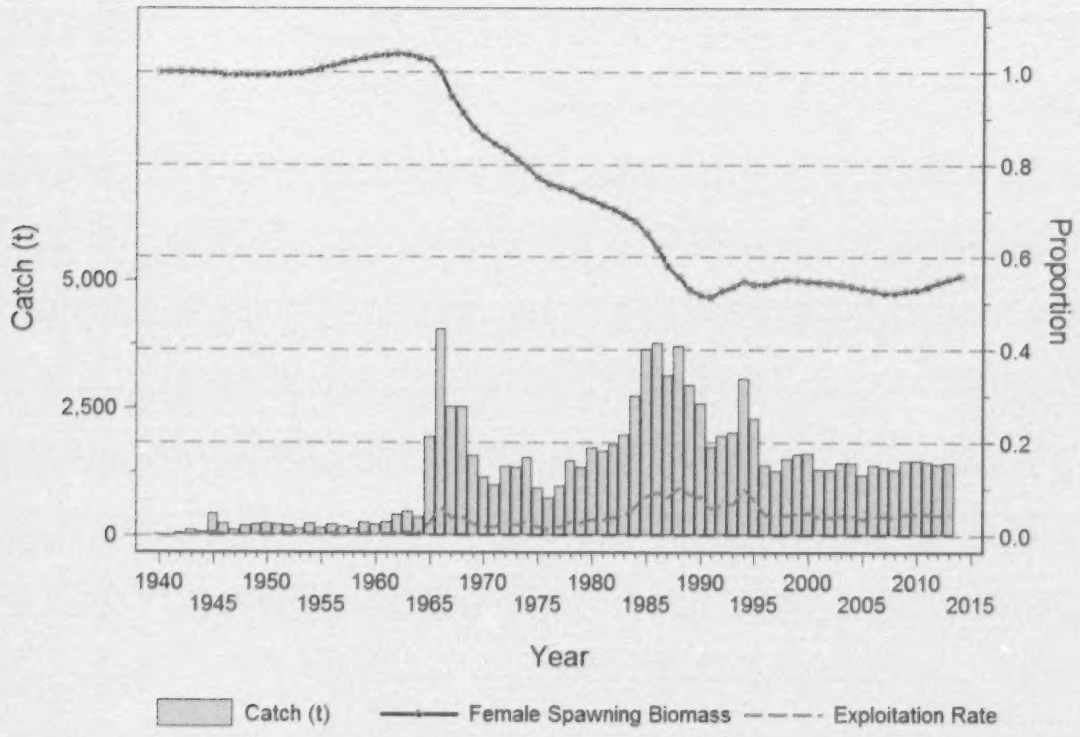

Figure 5. Median female spawning biomass trajectory relative to catch and median exploitation rate. Annual commercial catch (vertical bars) are plotted from the left-hand axis while the median Bayesian estimates for B_t/B_0 and u_t/V_t (where V_t is the vulnerable biomass of males plus females in year t) are plotted as proportions on the right-hand axis.

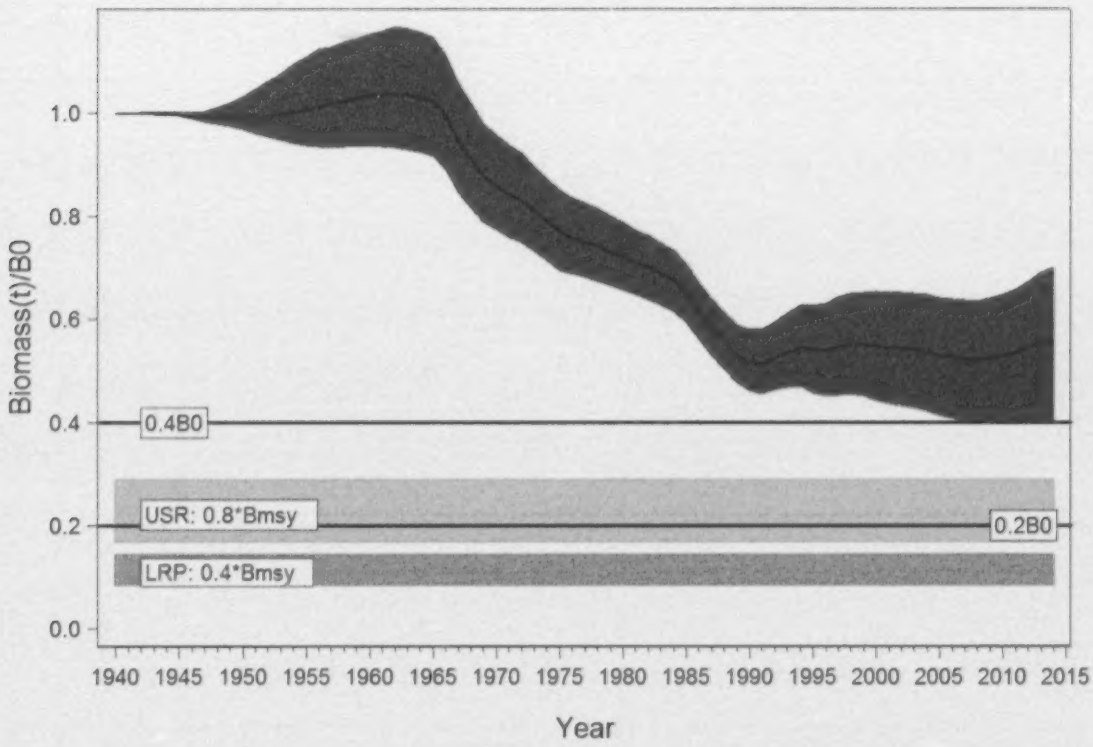

Figure 6. Posterior median estimates and 90% credibility intervals for female spawning biomass by year relative to B_0 for Silvergray Rockfish (black line and grey fill). Also shown are posterior median estimates and 90% credibility intervals for the MSY-based reference points (LRP: Limit Reference Point = $0.4B_{MSY}$; USR: Upper Stock Reference Point = $0.8B_{MSY}$) relative to B_0. The B_0 reference points: $0.2B_0$ and $0.4B_0$ are shown as solid black lines.

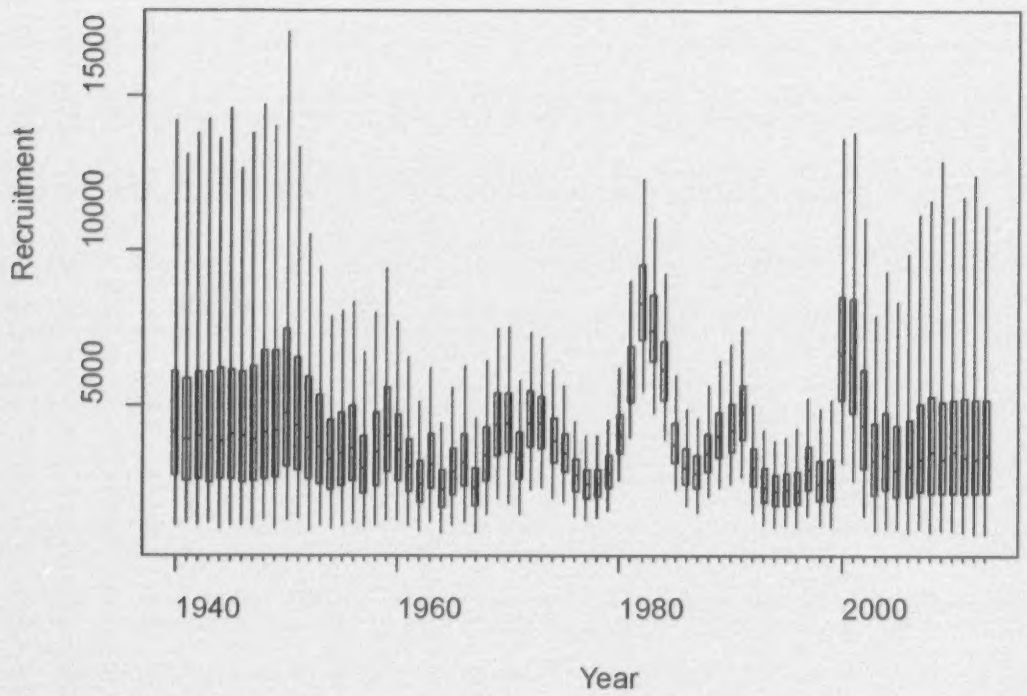

Figure 7. Boxplots of the marginal posterior distribution of recruitment in 1,000's of age-1 fish plotted by year for the Silvergray Rockfish base case run. Boxplots show the 2.5, 25, 50, 75 and 97.5 quantiles from the MCMC posterior.

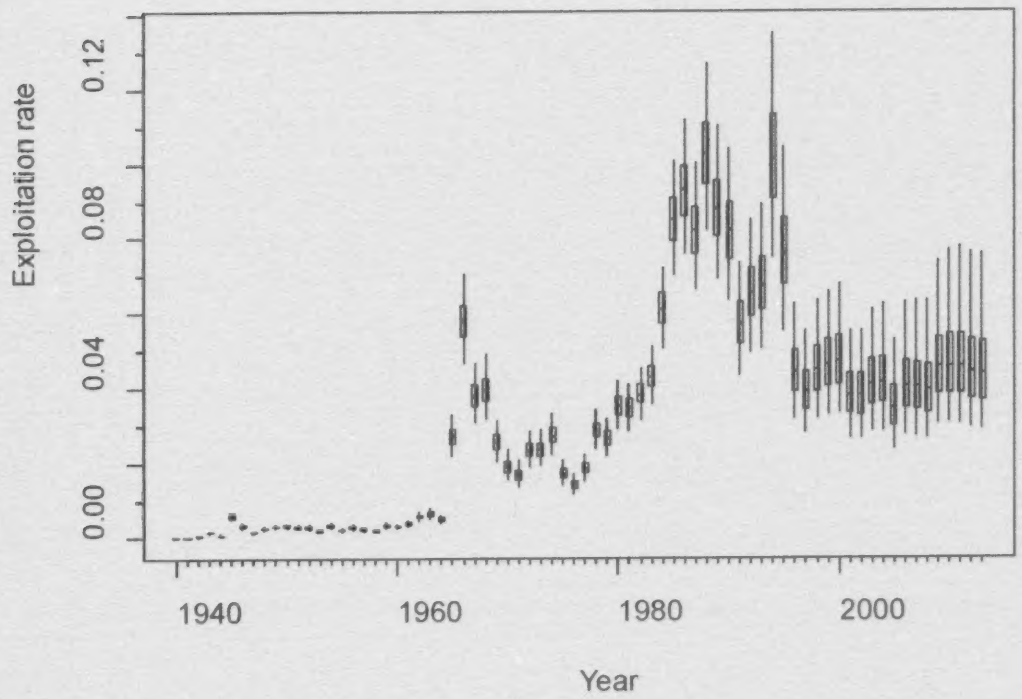

Figure 8. Boxplots of the marginal posterior distribution of annual mid-year exploitation rate plotted by year for the Silvergray Rockfish base case run. Boxplots show the 2.5, 25, 50, 75 and 97.5 quantiles from the MCMC posterior.

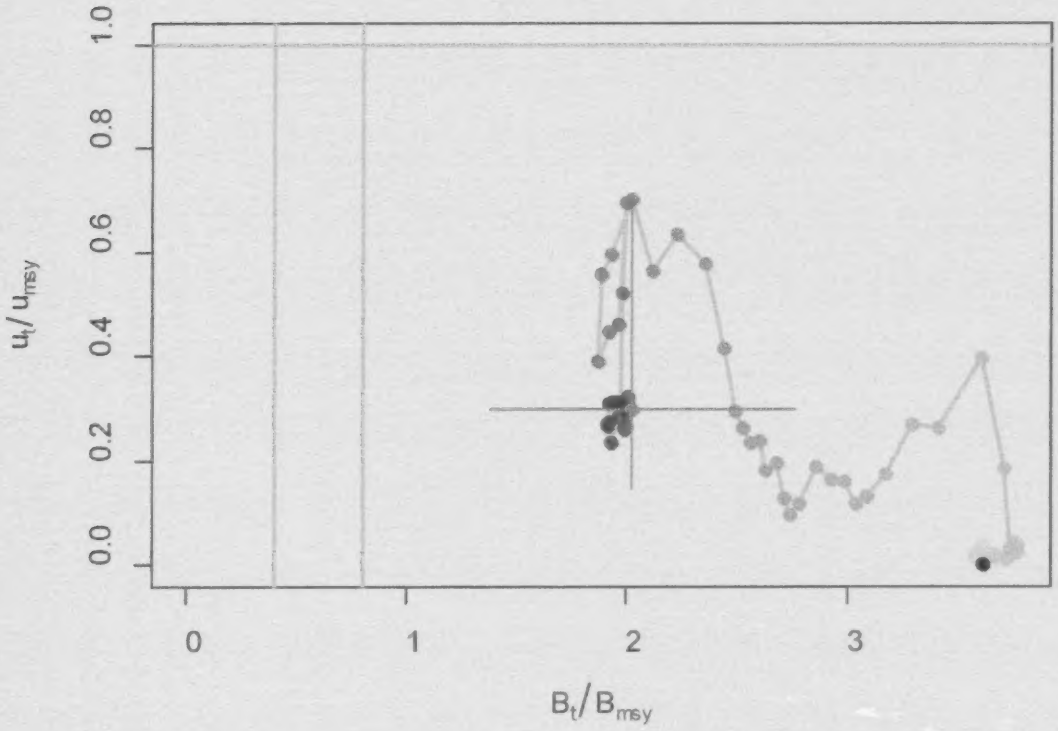

Figure 9. Phase plot by year of the medians of the ratios B_t/B_{MSY} and u_t/u_{MSY} for the Silvergray Rockfish base case run. Blue filled circle is the starting year (1940). Years proceed from light grey to dark grey with the red circle showing the beginning year 2014 biomass with 10% and 90% quantiles from the posterior distribution. Vertical grey lines indicate the SFF DFO limit and upper stock reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$, and the horizontal grey line indicates u_{MSY}.

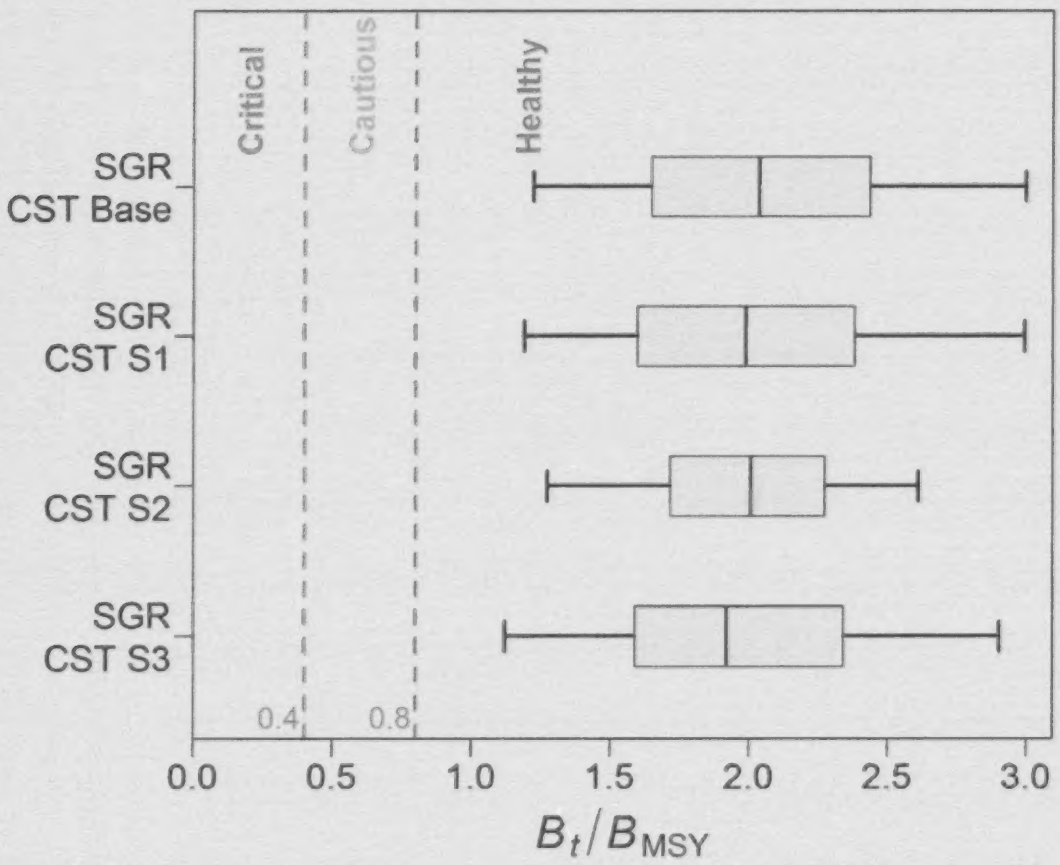

Figure 10. Status at beginning of 2014 of the Silvergray Rockfish coastwide stock relative to the DFO PA provisional reference points of $0.4B_{MSY}$ and $0.8B_{MSY}$ for the base case stock assessment and three sensitivity runs (S1=fix M=0.06; S2=Stage 2+ maturity ogive; S3=non-informative priors on four survey selectivity parameters). Boxplots show the 2.5, 25, 50, 75 and 97.5 quantiles from the MCMC posterior. Appendix F contains the details of these sensitivity runs.

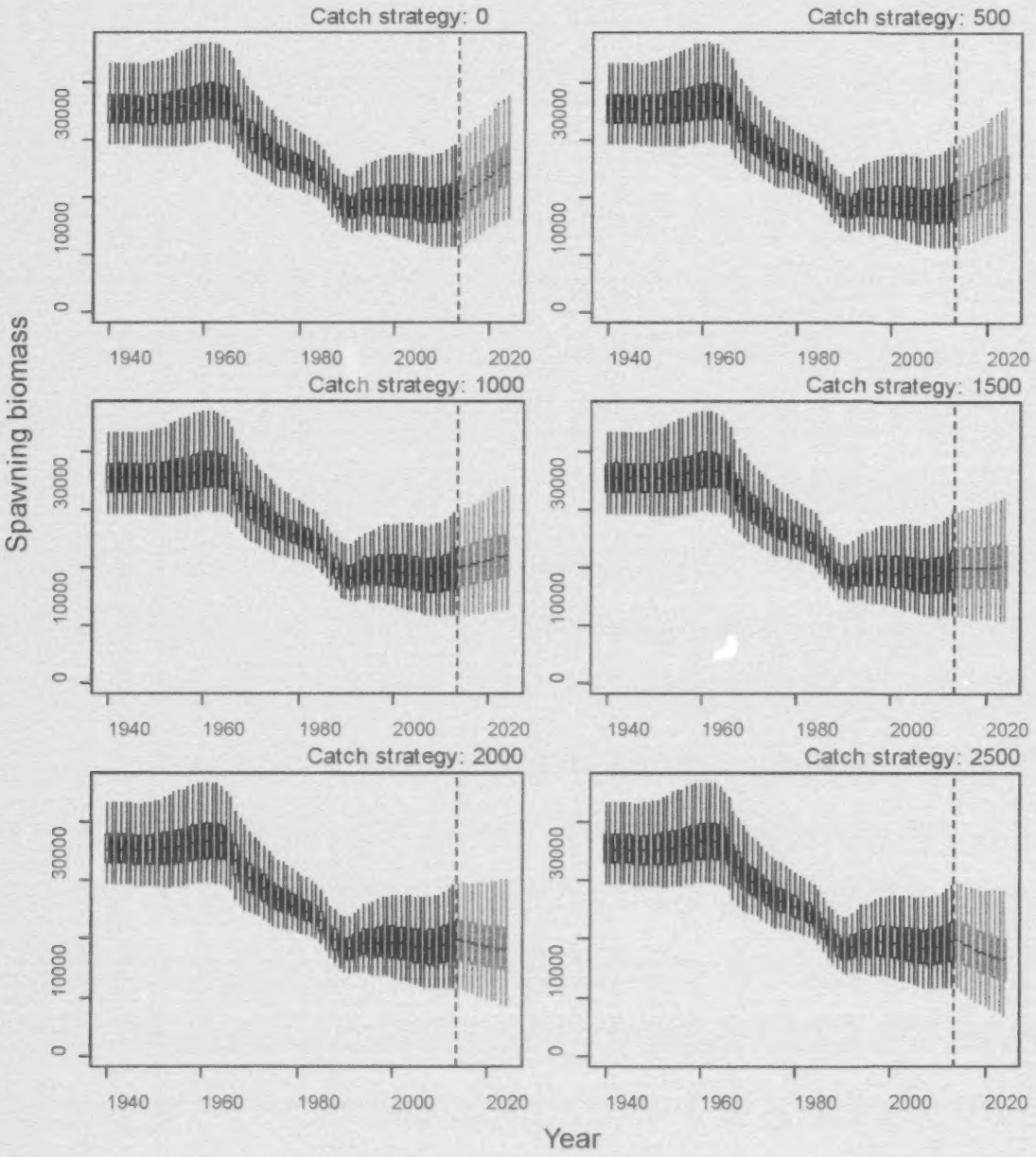

Figure 11. Projected biomass (t) under different constant catch strategies (t); boxplots show the 2.5, 25, 50, 75 and 97.5 quantiles from the MCMC posteriors for the Silvergray Rockfish base case run. For reference, the average catch over the last 5 years (2008-2012) is 1,408t/year.

14. TABLES

Table 1A. Prior distributions for estimated parameters in the Bayesian estimation procedure. Symbols correspond to the notation used to describe the stock assessment model structure in Appendix D.

Parameter	Symbol	Prior Distribution
Unfished equilibrium recruitment	R_0	Uniform (1, 100 000)
Recruitment deviations (log scale)	σ_R	Normal (0, 0.6)
Natural mortality	M	Normal (0.06, 0.006)
Steepness	h	Beta (4.574, 2.212)
Survey catchability (log-scale)	$\ln(q)$	Uniform (-5, 5)

Table 1B. Prior distributions for each estimated survey selectivity function and for the commercial fishery selectivity function in the Bayesian estimation procedure.

Parameter	Survey/fishery	Symbol	Prior Distribution	Reference
Age at full selectivity	WCHG synoptic	$\mu_{WCHGsyn}$	Normal (10.8, 3.24)	Edwards et al. 2014a
	HS synoptic	μ_{HSsyn}	Normal (10.8, 3.24)	Edwards et al. 2014a
	QCS synoptic	μ_{QCSsyn}	Normal (13.3, 4)	Edwards et al. 2012b
	WCVI synoptic	$\mu_{WCVIsyn}$	Normal (15.4, 4.62)	Edwards et al. 2014b
	GB Reed historical	$\mu_{GBReedHist}$	fixed=12.4	Edwards et al. 2012b
	US Triennial	$\mu_{USTrienn}$	fixed=15.4	Edwards et al. 2014b
	Commercial fishery	$\mu_{fishery}$	Uniform (5, 32)	
"shift" for males from female selectivity mode	WCHG synoptic	$D_{WCHGsyn}$	Normal (0.22, 0.066)	Edwards et al. 2014a
	HS synoptic	D_{HSsyn}	Normal (0.22, 0.066)	Edwards et al. 2014a
	QCS synoptic	D_{QCSsyn}	Normal (0.22, 0.066)	Edwards et al. 2012b
	WCVI synoptic	$D_{WCVIsyn}$	Normal (0.22, 0.066)	Edwards et al. 2014b
	GB Reed historical	$D_{GBReedHist}$	fixed=0.39	Edwards et al. 2012b
	US Triennial	$D_{USTrienn}$	fixed=0.22	Edwards et al. 2014b
	Commercial fishery	$D_{fishery}$	Uniform (-6, 6))	
Left side variance (log-scale)	WCHG synoptic	$v_{L\ WCHGsyn}$	Normal (2.08, 0.62)	Edwards et al. 2014a
	HS synoptic	$v_{L\ HSsyn}$	Normal (2.08, 0.62)	Edwards et al. 2014a
	QCS synoptic	$v_{L\ QCSsyn}$	Normal (3.3, 1)	Edwards et al. 2012b
	WCVI synoptic	$v_{L\ WCVIsyn}$	Normal (3.44, 1.03)	Edwards et al. 2014b
	GB Reed historical	$v_{LGBReedHist}$	fixed=3.52	Edwards et al. 2012b
	US Triennial	$v_{L\ USTrienn}$	fixed=3.44	Edwards et al. 2014b
	Commercial fishery	$v_{L\ fishery}$	Uniform(-15, 15)	

Table 2. The 5th, 50th and 95th quantiles of the MCMC posterior distributions for the main estimated model parameters for the base case Silvergray Rockfish coastwide stock assessment.

	Percentile		
Value	5%	50%	95%
R_0	3,153	4,194	5,492
M_F	0.05607	0.06324	0.06925
M_M	0.04563	0.05142	0.05743
h	0.5076	0.7499	0.9309
$q_{WCHGsyn}$	0.02467	0.03747	0.06008
q_{HSsyn}	0.007014	0.009638	0.01535
q_{QCSsyn}	0.08021	0.1243	0.1944
$q_{WCVIsyn}$	0.01189	0.02107	0.03613
$q_{GBReedHist}$	0.01513	0.02200	0.03185
$q_{USTrienn}$	0.02114	0.03290	0.05135
$\mu_{WCHGsyn}$	14.49	15.94	17.61
μ_{HSsyn}	8.607	10.54	12.99
μ_{QCSsyn}	14.66	16.83	20.10
$\mu_{WCVIsyn}$	14.57	19.27	23.90
$\mu_{fishery}$	16.37	17.26	18.26
$D_{WCHGsyn}$	0.1086	0.2186	0.3237
D_{HSsyn}	0.1107	0.2219	0.3232
D_{QCSsyn}	0.1130	0.2187	0.3244
$D_{WCVIsyn}$	0.1071	0.2161	0.3242
$D_{fishery}$	-0.002717	0.6623	1.259
$v_{L\ WCHGsyn}$	1.079	1.950	2.740
$v_{L\ HSsyn}$	1.171	2.178	3.111
$v_{L\ QCSsyn}$	2.148	3.048	3.858
$v_{L\ WCVIsyn}$	3.276	4.263	4.949
$v_{L\ fishery}$	2.605	2.945	3.269

Table 3. The 5th, 50th and 95th quantiles of MCMC posterior distributions for model and MSY-based derived parameters for the base case Silvergray Rockfish coastwide stock assessment. B_0: unfished female equilibrium spawning biomass; V_0: unfished equilibrium vulnerable biomass, combined males and females; B_{2014}: spawning biomass at beginning of 2014; V_{2014}: vulnerable biomass at beginning of 2014, combined males and females; u_{2013}: exploitation rate in mid-year 2013, B_{MSY}: equilibrium female spawning biomass at MSY (maximum sustainable yield), u_{MSY}: equilibrium exploitation rate at MSY. All biomass values and MSY are in tonnes. The average catch over the 5 years (2008-2013) is 1408 t.

	Model derived parameters		
B_0	30,135	35,387	41,926
V_0	60,849	69,565	81,206
B_{2014}	12,669	19,803	28,070
V_{2014}	20,759	32,832	47,679
B_{2014} / B_0	0.405	0.559	0.698
V_{2014} / V_0	0.334	0.474	0.601
u_{2013}	0.030	0.044	0.068
	MSY-based derived parameters		
B_{MSY}	7,089	9,718	13,717
$0.4B_{MSY}$	2,836	3,887	5,487
$0.8B_{MSY}$	5,671	7,774	10,974
B_{2014} / B_{MSY}	1.223	2.035	2.997
MSY	1,299	1,998	2,688
u_{MSY}	0.064	0.145	0.300
u_{2013}/u_{MSY}	0.127	0.298	0.883

Table 4. Decision table for 5-year projections for the base case coastwide Silvergray Rockfish stock assessment. Values are the probability that biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2019 under a given constant annual catch policy. Decision tables showing probabilities of exceeding reference points for every year between 2014 and 2019 are provided in Appendix E.

Catch	$P(B_{2019} > 0.4B_{MSY})$	$P(B_{2019} > 0.8B_{MSY})$	$P(B_{2019} > B_{MSY})$	$P(B_{2019} > B_{2014})$	$P(u_{2019} > u_{MSY})$	$P(B_{2019} > 0.2B_0)$	$P(B_{2019} > 0.4B_0)$
0	1.00	1.00	1.00	1.00	0.00	1.00	0.99
250	1.00	1.00	0.99	1.00	0.00	1.00	0.99
500	1.00	1.00	0.99	0.99	0.00	1.00	0.99
750	1.00	1.00	0.99	0.95	0.00	1.00	0.98
1000	1.00	1.00	0.99	0.87	0.01	1.00	0.97
1250	1.00	1.00	0.99	0.71	0.02	1.00	0.96
1500	1.00	0.99	0.98	0.52	0.04	1.00	0.95
1750	1.00	0.99	0.98	0.36	0.07	1.00	0.93
2000	1.00	0.99	0.97	0.22	0.11	1.00	0.90
2250	1.00	0.99	0.96	0.12	0.16	1.00	0.86
2500	1.00	0.98	0.95	0.07	0.22	1.00	0.83
2750	1.00	0.98	0.94	0.04	0.28	1.00	0.79
3000	1.00	0.97	0.92	0.02	0.33	0.99	0.76

Table 5. Decision table for 10 year projections for the base case coastwide Silvergray Rockfish stock assessment. Values are the probability that biomass, B, (or exploitation rate, u), is greater than the specified reference point in 2024 under a given constant annual catch policy. Decision tables showing probabilities of exceeding reference points for every year between 2020 and 2024 are provided in Appendix E.

Catch	$P(B_{2024} > 0.4B_{MSY})$	$P(B_{2024} > 0.8B_{MSY})$	$P(B_{2024} > B_{MSY})$	$P(B_{2024} > B_{2014})$	$P(u_{2024} > u_{MSY})$	$P(B_{2024} > 0.2B_0)$	$P(B_{2024} > 0.4B_0)$
0	1.00	1.00	1.00	1.00	0.00	1.00	1.00
250	1.00	1.00	1.00	1.00	0.00	1.00	1.00
500	1.00	1.00	1.00	0.99	0.00	1.00	0.99
750	1.00	1.00	0.99	0.95	0.00	1.00	0.99
1000	1.00	1.00	0.99	0.86	0.01	1.00	0.98
1250	1.00	1.00	0.98	0.72	0.02	1.00	0.97
1500	1.00	0.99	0.98	0.54	0.04	1.00	0.94
1750	1.00	0.99	0.97	0.37	0.08	1.00	0.90
2000	1.00	0.98	0.95	0.22	0.14	1.00	0.84
2250	1.00	0.98	0.92	0.13	0.21	0.99	0.77
2500	0.99	0.96	0.89	0.08	0.28	0.98	0.69
2750	0.99	0.93	0.85	0.05	0.36	0.97	0.62
3000	0.99	0.89	0.80	0.02	0.44	0.95	0.53

APPENDIX A. CATCH

A.1 BRIEF HISTORY OF THE FISHERY

The early history of the British Columbia (BC) trawl fleet is discussed by Forrester and Smith (1972). A trawl fishery for slope rockfish has existed in BC since the 1940s. Aside from Canadian trawlers, foreign fleets targeted Pacific Ocean Perch (POP, *Sebastes alutus*) in BC waters for approximately two decades. These fleets were primarily from the US (1959–1980), the USSR (1965–1968), and Japan (1966–1976). The foreign vessels removed large amounts of rockfish biomass (presumably Silvergray Rockfish included), particularly in Queen Charlotte Sound (5ABC).

Prior to 1977, no quotas were in effect for any slope rockfish species. Since then, the groundfish management unit (GMU) at the Department of Fisheries and Oceans (DFO) has imposed a combination of species/area quotas, area/time closures, and trip limits on the major species. Quotas were first introduced for Silvergray Rockfish (SGR) in 1983 for GMU area 5CD (Tables A.1 and A.2).

Stanley and Kronlund (2000) provide an exhaustive description of the management and catch landings of Silvergray Rockfish along the BC coast. Essentially, this document uses the same data sources as those in previous Silvergray assessments (e.g., Ketchen 1976, 1980a,b, and the DFO databases GFCatch, PacHarvest, PacHarvHL, PacHarvSable, and GFFOS); however, the methodolgy in Haigh and Yamanaka (2011) differs from the compilations of the past. That said, the catches reported by Stanley and Kronlund (2000) during the years of foreign fleet activity (~2,000 t annually) do not differ hugely from the catches reported herein. Perhaps the only departure is a spike in 1966 at 4000 t when all foreign fleets (Russian, Japanese, American) were active, and the Russians were removing huge amounts of rockfish (Ketchen, 1980b).

A.2 CATCH RECONSTRUCTION

Unlike the last Silvergray Rockfish assessment (Stanley and Olsen, 2002), we do not use fishing year for population models, and so catch estimates are made by calendar year. As with the previous assessment, we do use "official" catch numbers whenever they have been prepared in the various modern catch databases. Essentially this means that DMP (dockside monitored) landings are treated as official, but the composition of each DMP landings is prorated to reflect the observer log records of catch by species and area, when they exist. These data comprise one set of inputs to the catch reconstruction.

A detailed account of how we reconstruct rockfish catch on the BC coast can be found in Haigh and Yamanaka (2011). The algorithm uses eight historical data sources (the earliest extending back to 1918) and five modern catch databases housed at various DFO facilities. The historical data comprise landings statistics for two broad categories of rockfish – Pacific Ocean Perch (POP) and rockfish other than POP (ORF). The sum of these two combine to form total rockfish (TRF) landings.

In a previous stock assessment for Pacific Ocean Perch, Edwards et al. (2014) documented two departures from the catch reconstruction algorithm in Haigh and Yamanaka (2011). The first drops the use of trawl and trap data from the sales slip database PacHarv3 because catches are sometimes reported by large statistical areas that cannot be clearly mapped to PMFC areas. PacHarv3 should report the same catch as that in the GFCatch database Rutherford (1999), but

area inconsistencies cause catch inflation when certain large statistical areas cover multiple PMFC areas. Therefore, we only use the GFCatch database for the trawl and trap records from 1954 to 1995, rather than trying to mesh GFCatch and PacHarv3. The second departure is the inclusion of an additional data source for Japanese rockfish catch reported in Ketchen (1980a).

For Silvergray Rockfish, catch and discards are known fully from 1996 on. Prior to this period, the reconstruction algorithm calculates landings and discards using ratios from reference years 1997–2005 when catch information was relatively well-recorded for all rockfish species, especially by the trawl fleet with its onboard observers. Composition ratios are used to disaggregate one of the broad rockfish categories (TRF, ORF, or POP) in the historical series. For Silvergray Rockfish, we use the ratio SGR/TRF. Historical discard rates are also estimated based on recent discard rates. The reconstruction provides catches (landings + discards) by calendar year, fishery (Trawl, Halibut, Sablefish, Dogfish-Lingcod, Hook & Line Rockfish), and Pacific Marine Fisheries Commission (PMFC) major areas in BC (4B, 3C, 3D, 5A, 5B, 5C, 5D, 5E). There are numerous decisions made during the reconstruction procedure that affect the final outcome, e.g., to allocate the annual catch U_t (for year t) from unknown areas to each PMFC area i using the proportions $C_{ti}/\sum_{i \in \text{PMFC}} C_{ti}$ of known catch C_{ti} in PMFC area i. But decisions made include all identified removals whenever possible. This procedure includes currently available sources of commercial removals; research survey catches are tallied separately and added to the commercial catches (not presented here).

This assessment reconstructs catch back to 1940 (Figure A.1, Table A.3) when the fishery increased during World War II. From 1918 to 1939, removals were negligible compared to those that came after 1939. During the period 1950–1975, US vessels routinely caught more rockfish than did Canadian vessels. Additionally, from the mid-1960s to the mid-1970s, foreign fleets (Russian and Japanese) removed large amounts of rockfish, primarily POP. These large catches were first reported by various authors (Westrheim et al., 1972; Gunderson et al., 1977; Leaman and Stanley, 1993); however, Ketchen (1980b) re-examined the foreign fleet catch, primarily because statistics from the USSR called all rockfish 'perches' while the Japanese used the term 'Pacific ocean perch' indiscriminately. The catch of Silvergray Rockfish jumps dramatically in 1965, which reflects the foreign fleet targeting POP and the catch algorithm's calculations using catch ratios of SGR/TRF. Obviously, a caveat to this procedure is that ratios of Silvergray Rockfish to total rockfish derived from the modern fishery will likely not reflect the catch ratios during the historical foreign fleet activity.

The accuracy and precision of reconstructed catch series inherently reflect the problems associated with the development of a commercial fishery: trips offloading catch with no area information, unreported discarding, recording catch of one species as another to avoid quota violations, developing expertise in monitoring systems, shifting regulations, changing data storage technologies, etc. Many of these problems have been solved through the introduction of onboard observer programs (started in 1996 for the offshore trawl fleet), dockside monitoring, and tradable individual vessel quotas (IVQs, 1997) that confer ownership of the resource to the fishing sector. Improvements in data storage and retrieval technologies are still ongoing.

Table A.1. Annual trawl Total Allowable Catches (TACs) in tonnes for Silvergray Rockfish in Groundfish Management areas. Year can either be calendar year (1979-1996) or fishing year (1997 on). See Table A.2 for explanation of Notes column.

Year	3CD	5AB	5CD	5E	Coast	Notes
1979	—	—	—	—	–	a
1980	—	—	—	—	–	
1981	—	—	—	—	–	c
1982	—	—	—	—	–	
1983	—	—	300	—	300	
1984	—	—	600	—	600	
1985	—	—	600	—	600	
1986	—	—	—	—	–	
1987	—	—	600	—	600	
1988	—	—	600	—	600	
1989	500	850	650	—	2,000	
1990	—	—	—	—	–	f
1991	—	—	—	—	–	g,h
1992	—	—	—	—	–	i
1993	—	—	—	—	–	
1994	—	—	—	—	–	l
1995	—	—	—	—	–	m
1996	—	—	—	—	–	n,o
1997	331	604	302	273	1,510	p,q
1998	331	604	302	273	1,510	
1999	328	599	300	271	1,498	
2000	301	549	275	248	1,373	r,s
2001	272	496	248	224	1,240	B
2002	272	443	248	224	1,187	B,u,v
2003	216	421	382	248	1,267	B
2004	216	421	382	248	1,267	
2005	216	421	382	248	1,267	
2006	244	476	432	281	1,433	x,y,z
2007	244	476	432	281	1,433	
2008	244	476	432	281	1,433	
2009	244	476	432	281	1,433	
2010	244	476	432	281	1,433	
2011	244	476	432	281	1,433	
2012	244	476	432	281	1,433	
2013	244	476	432	281	1,433	

Table A.2. Codes to notes on management actions and quota adjustments that appear in Table A.1.

Code	Management Actions
a	Started limited vessel entry for Halibut fleet.
c	Started limited vessel entry for Sablefish fleet.
f	Started *Individual Vessel Quotas* (IVQ) systems for Halibut and Sablefish.
g	Started *Dockside Monitoring Program* (DMP) for the Halibut fleet.
h	Started limited vessel entry for *Hook and Line* (H&L) fleet inside.
i	Started limited vessel entry for H&L fleet outside.
l	Started DMP for Trawl fleet.
m	Implemented catch limits (monthly) on rockfish aggregates for H&L.
n	Started 100% onboard observer program for offshore Trawl fleet.
o	Started DMP for H&L fleet.
p	Started IVQ system for Trawl *Total Allowable Catch* (TAC) species (April 1, 2007)
q	Implemented catch limits (15,000 lbs per trip) on combined non-TAC rockfish for the Trawl fleet.
r	Implemented catch limits (20,000 lbs per trip) on rockfish aggregates for the Halibut option D fleet.
s	Implemented formal allocation of rockfish species between Halibut and H&L sectors.
u	Established the inshore rockfish conservation strategy.
v	Closed areas to preserve four hexactinellid (glassy) sponge reefs.
x	Introduced an *Integrated Fisheries Management Plan* (IFMP) for most groundfish fisheries.
y	Started 100% at-sea electronic monitoring for H&L.
z	Implemented mandatory retention of rockfish for H&L.
B	The Department has adopted the conservative F=M harvest strategy in establishing the Silvergray Rockfish TAC for all areas except 5AB. In 5AB the TAC will be stepped downward by 60 tonnes annually for each of the 2001/2002, 2003/2004 and 2003/2004 seasons to achieve this harvest strategy.

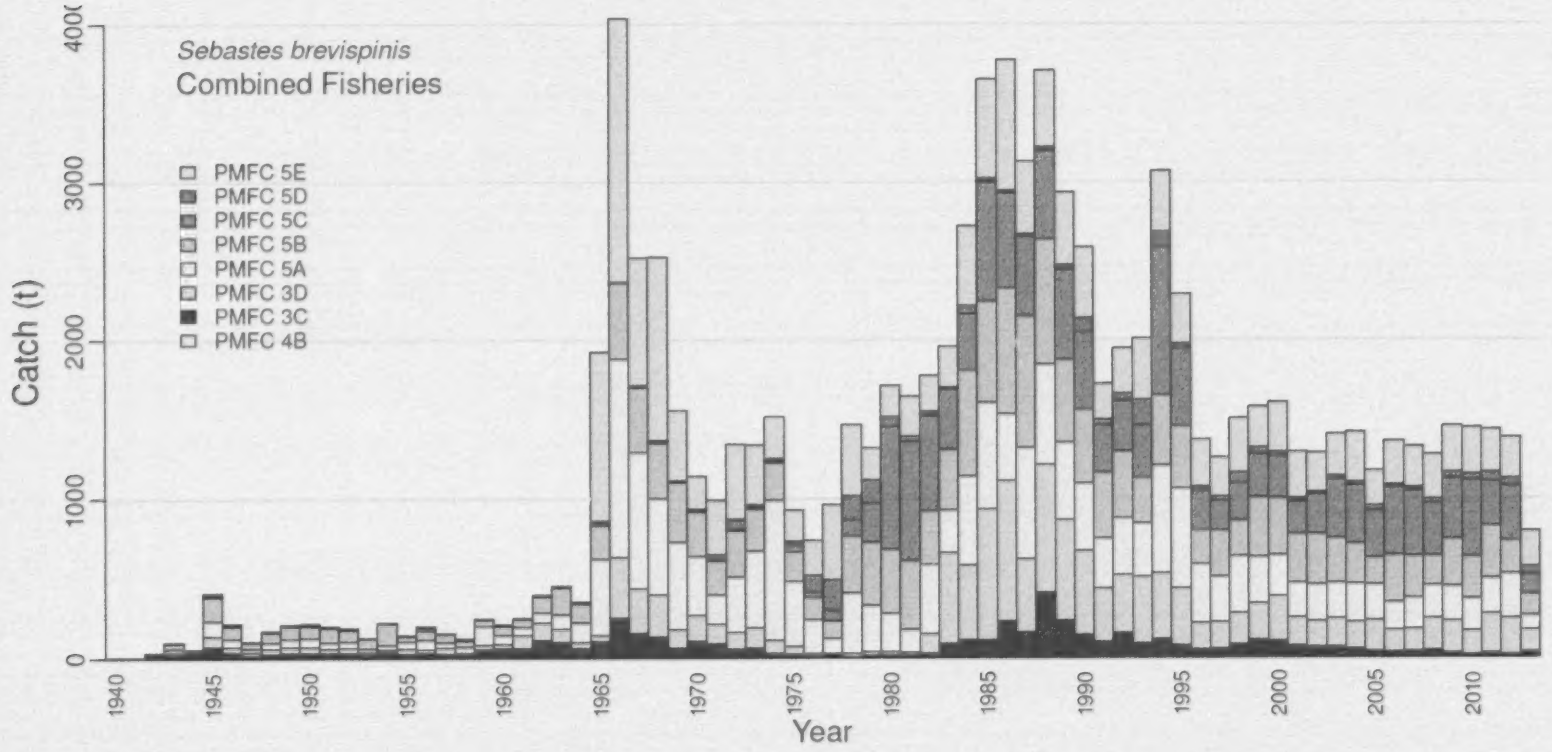

Figure A.1. Reconstructed total (landed + discarded) catch (t) for Silvergray Rockfish from all fisheries combined in all PMFC major areas along the BC coast.

Table A.3. Catch reconstruction (landings + discards, tonnes) for Silvergray Rockfish in PMFC major areas 3CD, 5AB, 5CD, 5E, and Total (includes 4B) in the Trawl and Hook & Line (Halibut, Sablefish, Dogfish–Lingcod, H&L Rockfish) fisheries. Catch for 2013 remains incomplete (records accessed July 18, 2013).

Year	Trawl					Hook & Line				
	3CD	5AB	5CD	5E	Total	3CD	5AB	5CD	5E	Total
1940	1.34	2.41	0.342	0	4.57	0.0404	0.0606	0.0519	0.0299	0.436
1941	0.839	1.25	1.32	0	3.70	0.149	0.343	0.329	0.190	1.17
1942	9.96	17.5	2.15	0	30.2	0.374	0.395	0.288	0.166	1.58
1943	31.6	56.2	6.28	0	98	0.979	1.04	0.759	0.438	5.27
1944	15.4	24.2	5.36	0	50.7	1.29	1.39	1.03	0.595	7.37
1945	129	243	21	0	400	1.01	1.81	1.64	0.947	8.69
1946	66.2	124	16.5	0	211	0.886	2.39	2.37	1.37	9.22
1947	34.1	63.9	5.36	0	105	0.284	0.448	0.390	0.225	2.05
1948	55.4	104	8.55	0	170	0.432	0.681	0.593	0.343	3.12
1949	67.5	126	10.7	0	207	0.575	0.907	0.790	0.456	4.16
1950	70.1	131	13.6	0	216	0.245	0.386	0.336	0.194	1.77
1951	58.7	126	9.74	0	196	0.806	1.67	2.34	1.19	6.45
1952	64	114	8.67	0	188	0.573	1.83	1.08	0.792	4.62
1953	38.7	83.9	3.15	0	126	0.301	1.13	0.314	0.0962	2.26
1954	56.4	160	4.69	0	222	0.368	0.722	0.378	0.175	1.91
1955	57	82.8	5.12	0	146	0.413	0.184	0.228	0.215	1.30
1956	54.3	119	24	0	198	0.418	0.333	0.0522	0.0585	1.11
1957	64.2	85.1	7.54	0	157	0.701	0.338	0.115	0.300	1.88
1958	31.4	80.6	7.99	0	121	0.612	0.0831	0.0253	0.0198	1.36
1959	78.2	158	5.60	0	244	0.680	0.188	0.0113	0.0283	1.55
1960	87.1	109	13.8	0	212	0.755	0.802	0.400	0.0849	2.56
1961	144	96.6	7.64	0	249	0.962	0.730	0.141	0.0962	2.32
1962	218	164	11.4	0	395	1.22	0.911	0.490	0.0792	3.32
1963	183	254	13	0	451	0.782	2.01	0.387	0.394	4.05
1964	98.5	238	11.2	0	349	0.530	0.548	0.102	0.0321	1.50
1965	143	691	26.6	1,060	1,921	0.440	0.261	0.275	0.253	1.49
1966	630	1,730	5.89	1,666	4,033	0.507	0.628	0.263	0.126	1.73
1967	434	1,262	13.3	803	2,513	0.706	0.456	0.770	0.146	2.40
1968	397	950	13.8	1,157	2,519	0.575	0.327	0.121	0.0198	1.39
1969	179	917	13.2	443	1,553	0.642	1.55	0.519	0.00849	3.13
1970	264	648	17.5	204	1,134	0.846	1.74	2.01	0.00754	5.10
1971	210	399	35.3	338	983	0.311	1.74	1.80	0.0462	4.32
1972	162	634	69.3	473	1,339	1.23	2.03	1.69	0.0868	5.51
1973	190	744	26.4	372	1,332	0.592	1.53	1.52	0.123	4.34
1974	111	1,110	29.6	258	1,508	0.899	1.13	3.11	0.0189	5.44
1975	69.5	595	63.9	194	922	0.731	1.71	3.73	0.189	6.59
1976	28	347	141	219	736	0.748	1.90	1.63	0.189	4.74
1977	28.5	200	257	468	953	0.895	5.03	2.12	0.151	8.97
1978	26.6	732	253	444	1,456	0.795	3.01	3.74	0.582	9
1979	36.2	684	385	199	1,305	1.59	5.15	3.59	1.08	12.8
1980	36.4	637	831	193	1,698	1.48	3.78	3.86	1.33	11.5
1981	31.6	574	779	248	1,633	1.12	2.97	2.83	0.886	9
1982	150	763	625	224	1,764	0.983	5.17	1.69	1.82	11.3
1983	655	648	385	257	1,945	1.28	5.41	2.03	2.13	12.6
1984	574	1,217	411	495	2,698	1.88	7.94	2.63	5.76	20.2
1985	929	1,295	768	620	3,612	2.52	15.9	6.64	5.52	33.1

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Table A.3. Catch reconstruction (landings + discards, tonnes) for Silvergray Rockfish in PMFC major areas 3CD, 5AB, 5CD, 5E, and Total (includes 4B) in the Trawl and Hook & Line (Halibut, Sablefish, Dogfish–Lingcod, H&L Rockfish) fisheries. Catch for 2013 remains incomplete (records accessed July 18, 2013).

Year	Trawl					Hook & Line				
	3CD	5AB	5CD	5E	Total	3CD	5AB	5CD	5E	Total
1986	1,100	1,200	604	819	3,723	8.14	17.2	9.74	7.16	45.3
1987	608	1,501	508	446	3,063	8.51	28.7	13.5	8.18	61.3
1988	1,205	1,386	571	474	3,637	5.91	33.9	9.98	12.5	65.1
1989	856	975	589	446	2,866	7.52	33	10.8	12.8	66.6
1990	659	841	562	431	2,495	8.83	46.6	13	17.7	88.8
1991	424	686	323	205	1,638	9.06	43.1	13.4	16.9	85.2
1992	515	733	349	254	1,851	4.82	45.7	13.3	28.8	93.6
1993	484	590	474	328	1,877	20	31.8	17.5	61.1	133
1994	514	1,033	1,015	327	2,890	12.7	89.8	11.5	60.9	176
1995	429	949	509	246	2,134	8.31	66.3	9.04	72.2	156
1996	210	547	266	227	1,250	7.56	33.3	8.67	70	121
1997	219	553	210	208	1,190	3.27	22.6	6.25	35.6	68
1998	274	556	293	309	1,432	3.26	26.1	9.11	31.2	70
1999	325	631	298	216	1,470	16.9	36.3	12	41.1	107
2000	376	545	278	246	1,444	9.82	69	11.6	70.8	162
2001	245	451	213	216	1,124	6	72.5	12.3	78.1	170
2002	224	512	252	212	1,201	4.87	35.1	11.5	33.1	84.7
2003	244	460	382	235	1,321	4.08	42.5	9.59	24.6	80.8
2004	217	440	371	284	1,311	5.88	56.1	11.8	32.5	106
2005	230	348	316	189	1,083	6.51	41.6	11.8	31.9	91.9
2006	169	451	426	256	1,302	5.49	19.9	15.2	17.3	58
2007	176	438	416	235	1,264	4.18	18.9	16.3	19.7	59.2
2008	242	363	341	260	1,206	5.05	26.3	17	22.4	71.1
2009	226	491	414	265	1,395	2.87	24.1	6.98	22.7	56.8
2010	167	445	517	266	1,396	2.24	15.5	6.09	22.4	46.4
2011	265	535	328	250	1,378	8.78	19.8	4.03	21.9	54.6
2012	239	467	388	228	1,321	5.29	22.2	4.70	29	61.3
2013	172	213	168	212	764	3.46	10.1	2.22	12.2	28

Table A.4. Total annual catch (t) of Silvergray Rockfish by fishery and survey activity. The final column contains the coastwide catch used in the population model. Catch for 2013 remains incomplete (records accessed July 18, 2013).

Year	Trawl	Halibut	Sablefish	Dogfish-Lingcod	H&L Rockfish	Surveys	Total (model)
1940	4.57	0.126	0	0.00224	0.308	—	5.01
1941	3.70	0.552	0	0.0120	0.602	—	4.86
1942	30.2	0.644	0	0.0154	0.924	—	31.8
1943	98	1.84	0	0.0404	3.40	—	103
1944	50.7	2.50	0	0.0541	4.81	—	58
1945	400	3.22	0	0.0653	5.41	—	409
1946	211	4.01	0	0.0829	5.13	—	221
1947	105	0.779	0	0.0164	1.26	—	107
1948	170	1.19	0	0.0249	1.91	—	173
1949	207	1.58	0	0.0332	2.55	—	211
1950	216	0.672	0	0.0141	1.08	—	218
1951	196	3.47	0	0.0734	2.90	—	202
1952	188	2.07	0	0.0483	2.50	—	192
1953	126	0.649	0	0.0127	1.60	—	128
1954	222	0.756	0	0.0172	1.13	—	224
1955	146	0.572	0	0.0167	0.713	—	148
1956	198	0.379	0	0.0109	0.721	—	199
1957	157	0.804	0	0.0255	1.05	—	159
1958	121	0.461	0	0.0130	0.891	—	122
1959	244	0.508	0	0.0148	1.03	—	245
1960	212	0.905	0	0.0206	1.64	—	214
1961	249	0.825	0	0.0239	1.47	—	251
1962	395	1.25	0	0.0285	2.05	—	399
1963	451	1.39	0	0.0339	2.63	0.581	455
1964	349	0.530	0	0.0129	0.958	0.0621	350
1965	1,921	0.666	0	0.0182	0.805	0.747	1,924
1966	4,033	0.665	0	0.0167	1.05	2.58	4,037
1967	2,513	1.19	0	0.0240	1.19	7.37	2,523
1968	2,519	0.544	0	0.0136	0.835	0.469	2,521
1969	1,553	1.03	0	0.0164	2.08	0.796	1,557
1970	1,134	2.53	0	0.0290	2.55	1.09	1,140
1971	983	1.96	0	0.0185	2.35	1.18	989
1972	1,339	2.50	0.000204	0.0408	2.96	0.0662	1,344
1973	1,332	1.85	3.24	0.0265	2.47	2.19	1,338
1974	1,508	3.13	0	0.0346	2.28	3.17	1,517
1975	922	3.72	0.000219	0.0387	2.83	0.129	929
1976	736	2.27	0	0.0349	2.43	4.16	745
1977	953	2.84	0	0.0387	6.09	3.42	966
1978	1,456	4.29	0	0.0612	4.65	9.44	1,475
1979	1,305	4.94	0.000748	0.0907	7.77	23.3	1,341
1980	1,698	5.16	0.000219	0.102	6.20	5.74	1,715
1981	1,633	3.84	0.000170	0.0727	5.10	3.24	1,645
1982	1,764	6.61	0	0.0588	4.59	0.550	1,776
1983	1,945	7.58	2.84	0.0620	4.91	1.64	1,959
1984	2,698	13	4.19	0.157	7.03	7.21	2,725
1985	3,612	21.2	3.66	0.169	11.7	13.8	3,659
1986	3,723	25.6	0.897	0.577	18.2	13.3	3,781

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Table A.4. Total annual catch (t) of Silvergray Rockfish by fishery and survey activity. The final column contains the coastwide catch used in the population model. Catch for 2013 remains incomplete (records accessed July 18, 2013).

Year	Trawl	Halibut	Sablefish	Dogfish-Lingcod	H&L Rockfish	Surveys	Total (model)
1987	3,063	33	1.06	0.724	26.5	1.08	3,125
1988	3,637	31.9	0.942	0.719	31.6	10.5	3,713
1989	2,866	29.6	1.27	0.707	35	6.48	2,939
1990	2,495	35.7	0.715	0.823	51.6	1.76	2,585
1991	1,638	31.8	0.480	0.813	52.1	0.511	1,724
1992	1,851	32.4	0.445	0.890	59.8	0.0720	1,945
1993	1,877	42.1	0.841	1.05	88.6	3.35	2,013
1994	2,890	38.7	1.05	1.28	135	0.821	3,067
1995	2,134	10.3	1.03	0.275	145	1.06	2,292
1996	1,250	16.5	0.755	0.109	104	5.15	1,376
1997	1,190	18.2	1.03	0.517	48.2	8.93	1,267
1998	1,432	23.1	1.08	0.231	45.6	6.12	1,508
1999	1,470	24.6	1.07	0.535	80.5	0.806	1,578
2000	1,444	39.3	0.842	0.543	121	0.796	1,607
2001	1,124	53.8	0.890	2.67	113	0.0562	1,294
2002	1,201	49.6	0.659	1.70	32.8	2.59	1,288
2003	1,321	46.5	0.282	2.31	31.8	8.24	1,410
2004	1,311	60.8	0.449	1.69	43.4	6.51	1,423
2005	1,083	59.9	1.17	1.94	28.9	5.51	1,180
2006	1,302	45.5	0.249	0.650	11.6	15	1,375
2007	1,264	48.1	0.391	1.62	9.04	17.4	1,340
2008	1,206	52.5	2.01	2.64	14	16.4	1,294
2009	1,395	39.2	1.05	2.39	14.1	10.1	1,462
2010	1,396	27.7	1.12	1.29	16.3	11.9	1,454
2011	1,378	30.5	1.34	2.26	20.5	9.52	1,442
2012	1,321	41.1	2.17	2.26	15.7	23	1,406
2013	764	18.1	0.780	0.660	8.43	23.8	816

APPENDIX B. TRAWL SURVEYS

B.1. INTRODUCTION

This appendix summarises the derivation of relative Silvergray Rockfish (SGR) abundance indices from the:

- historical set of surveys operated in the Goose Island Gully of Queen Charlotte Sound (Section B.3);
- National Marine Fisheries Service (NMFS) Triennial survey operated off the lower half of Vancouver Island (Section B.6);
- Hecate Strait synoptic survey (Section B.6);
- Queen Charlotte Sound synoptic survey (Section B.7);
- west coast Vancouver Island synoptic survey (Section B.8);
- west coast Haida Gwaii synoptic survey (Section B.9).

B.2. ANALYTICAL METHODS

Catch and effort data for strata i in year y yield catch per unit effort (CPUE) values U_{yi}. Given a set of data $\{C_{yij}, E_{yij}\}$ for tows $j = 1, \ldots, n_{yi}$,

Eq. B.1
$$U_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{E_{yij}},$$

where C_{yij} = catch (kg) in tow j, stratum i, year y;

E_{yij} = effort (h) in tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

CPUE values U_{yi} convert to CPUE densities δ_{yi} (kg/km^2) using:

Eq. B.2
$$\delta_{yi} = \frac{1}{vw} U_{yi},$$

where v = average vessel speed (km/h);

w = average net width (km).

Alternatively, if vessel information exists for every tow, CPUE density can be expressed

Eq. B.3
$$\delta_{yi} = \frac{1}{n_{yi}} \sum_{j=1}^{n_{yi}} \frac{C_{yij}}{D_{yij} w_{yij}},$$

where C_{yij} = catch weight (kg) for tow j, stratum i, year y;

D_{yij} = distance travelled (km) for tow j, stratum i, year y;

w_{yij} = net opening (km) for tow j, stratum i, year y;

n_{yi} = number of tows in stratum i, year y.

The annual biomass estimate is then the sum of the product of CPUE densities and bottom areas across m strata:

Eq. B.4
$$B_y = \sum_{i=1}^{m} \delta_{yi} A_i = \sum_{i=1}^{m} B_{yi},$$

where δ_{yi} = mean CPUE density (kg/km^2) for stratum i, year y;

A_i = area (km^2) of stratum i;

B_{yi} = biomass (kg) for stratum i, year y;

m = number of strata.

The variance of the survey biomass estimate V_y (kg^2) follows:

Eq. B.5
$$V_y = \sum_{i=1}^{m} \frac{\sigma_{yi}^2 A_i^2}{n_{yi}} = \sum_{i=1}^{m} V_{yi},$$

where σ_{yi}^2 = variance of CPUE density (kg^2/km^4) for stratum i, year y;

V_{yi} = variance of the biomass estimate (kg^2) for stratum i, year y.

The coefficient of variation (CV) of the annual biomass estimate for year y is

Eq. B.6
$$CV_y = \frac{\sqrt{V_y}}{B_y}.$$

B.3. LIST OF AVAILABLE SURVEY INFORMATION FOR SILVERGRAY ROCKFISH

Table B.1. List of available surveys in the DFO GFBio database which have captured Silvergray Rockfish. Surveys highlighted in grey were included in this stock assessment.

Survey	First Year	Last Year	Number Years	N Years With Species	N Sets	N Sets With Species	Mean Catch/ Set
Queen Charlotte Sound Synoptic Survey	2003	2013	7	7	1,670	957	52.6 kg
Hecate Strait Multispecies Assemblage Survey	1984	2003	11	11	1,110	97	21.8 kg
Hecate Strait Synoptic Survey	2005	2013	5	5	854	253	14.8 kg
West Coast Vancouver Island Synoptic Survey	2004	2012	5	5	701	195	45.0 kg
Hecate Strait Pacific Cod Monitoring Survey	2002	2004	3	3	600	65	37.8 kg
West Coast Haida Gwaii Synoptic Survey	2006	2012	5	5	598	348	129.0 kg
Historic GB Reed Goose Island Gully Surveys	1967	1995	9	9	463	262	52.6 kg
Queen Charlotte Sound Shrimp Survey	1998	2012	15	15	1,036	184	14.9 kg
West Coast Vancouver Island Shrimp Survey	1975	2013	37	29	2,943	69	19.4 kg
West Coast Vancouver Island Thornyhead Survey	2001	2003	3	0	199	0	NA
IPHC Longline Survey	2003	2012	10	10	1,696	285	3.3 Pcs
PHMA Rockfish Longline Survey - Outside North	2006	2012	4	4	762	330	12.3 Pcs
PHMA Rockfish Longline Survey - Outside South	2007	2011	3	3	530	173	8.8 Pcs
IRF Longline Survey (North)	2003	2012	6	3	301	6	2.0 Pcs
IRF Longline Survey (South)	2005	2013	4	1	230	1	2.0 Pcs
Sablefish Inlet Standardized	1995	2010	16	0	317	0	NA
Sablefish Offshore Standardized	1990	2010	21	0	926	0	NA
Sablefish Stratified Random	2003	2010	8	3	672	3	1.3 Pcs

B.4. EARLY SURVEYS IN THE QUEEN CHARLOTTE SOUND GOOSE ISLAND GULLY

B.4.1. Data selection

Tow-by-tow data from a series of historical trawl surveys were available for 12 years spanning the period from 1965 to 1995. The first two surveys, in 1965 and 1966, were wide-ranging, with the 1965 survey extending from near San Francisco to halfway up the Alaskan panhandle ([left panel] Figure B.1). The 1966 survey was only slightly less ambitious, ranging from the southern US-Canada border in Juan de Fuca Strait into the Alaskan panhandle ([right panel] Figure B.1). It was apparent that the design of these two early surveys was exploratory and that these surveys would not be comparable to the subsequent Queen Charlotte Sound (QCS) surveys which were much narrower in terms of area covered and which had a much higher density of tows in the Goose Island Gully (GIG). This can be seen in the small number of tows used by the first two surveys in GIG (Table B.2).

The 1967 ([left panel]: Figure B.2) and 1969 ([left panel]: Figure B.3) surveys also performed tows on the west coast of Vancouver Island, the west coast of Haida Gwaii and SE Alaska, but both of these surveys had a reasonable number of tows in the GIG grounds (Table B.2). The 1971 survey ([left panel]: Figure B.4) was entirely confined to GIG while the 1973 ([left panel]: Figure B.5), 1976 ([left panel]: Figure B.6) and 1977 ([left panel]: Figure B.7) surveys covered both Goose Island and Mitchell Gullies in QCS.

A 1979 survey was conducted by a commercial fishing vessel (Southward Ho, Table B.2), with the distribution of tows being very different from the preceding and succeeding surveys (plot not provided; see Figure C.5 in Edwards et al. 2012b). As well, the distribution of tows by depth was also different from the other surveys (Table B.3). These observations imply a substantially different survey design and consequently this survey was not included in the time series used in the assessment.

The 1984 survey was conducted by two vessels: the GB Reed and the Eastward Ho. Part of the design of this survey was to compare the catch rates of the two vessels (one was a commercial fishing vessel and the other a government research vessel – Greg Workman, DFO, pers. comm.), thus they both followed similar design specifications, including the configuration of the net. Unfortunately, the tows were not distributed similarly in all areas, with the GB Reed fishing mainly in the shallower portions of the GIG, while the Eastward Ho fished more in the deeper and seaward parts of the GIG ([left panel]: Figure B.8) although the two vessels fished more contiguously in Mitchell Gully (immediately to the north). When the depth-stratified catch rates of the two vessels were compared within the GIG only (using a simple ANOVA), the Eastward Ho catch rates were significantly higher ($p=0.049$) than those observed for the GB Reed. However, the difference in catch rates was no longer significant when tows from Mitchell's Gully were added to the analysis ($p=0.12$). Given the lack of significance when the full suite of available tows were compared, along with the uneven spatial distribution of tows among vessels within the GIG (although the ANOVA was depth-stratified, it is possible that the depth categories were too coarse), the most parsimonious conclusion was that there was no detectable difference between the two vessels. Consequently, all the GIG tows from both vessels were pooled for this survey year.

The 1994 survey, also conducted by a commercial vessel (the Ocean Selector, Table B.3) ([left panel]: Figure B.9), was modified by the removal of 19 tows which were part of an acoustic experiment and therefore were not considered appropriate for biomass estimation (they were tows used to estimate species composition for ensonified schools). Although this survey was

designed to emulate as closely as possible the previous GB Reed surveys in terms of tow location selection (G. Workman, DFO, pers. comm.), the timing of this survey was about two to three months earlier than the previous surveys (starting in mid-June rather than August or September, Table B.4). The Technical Working Group agreed at a meeting in August 2013 that this difference in timing made this survey less appropriate for SGR (which tend to enter the fishery in the early autumn) and agreed to drop it from the base case assessment data set.

The 1995 survey, conducted by two commercial fishing vessels: the Ocean Selector and the Frosti (Table B.3), used a random stratified design with each vessel duplicating every tow ([left panel]: Figure B.10) (G. Workman, DFO, pers. comm.). This type of design was entirely different from that used in the previous surveys. As well, the focus of this survey was entirely on Pacific Ocean Perch (POP), with tows optimised to capture this species. The Technical Working Group agreed at a meeting in August 2013 that this difference in survey design and the emphasis on POP reduced the comparability of this survey with the earlier surveys and agreed to drop it from the base case assessment data set.

Given that the only area that was consistently monitored by these surveys was the GIG grounds, tows lying between 50.9°N and 51.6°N latitude from the seven acceptable survey years, covering the period from 1967 to 1984, were used to index the SGR population (Table B.2).

The original depth stratification of these surveys was in 20 fathom (36.1 m) intervals, with the important strata for SGR ranging from 70 fathoms (183 m) to 160 fathoms (300 m). For the GIG survey series, the shallowest tow capturing SGR was 121 m. Similarly, the deepest tow capturing SGR was 282 m. These depth strata were combined for analysis into three ranges: 70–100 fm, 100–120 fm and 120–160 fm, for a total of 282 tows from the seven accepted survey years (Table B.4).

A doorspread density (Eq. B.3) was calculated for each tow based on the catch of SGR, using a fixed doorspread value of 61.6 m (Yamanaka et al. 1996) for every tow and the recorded distance travelled. Unfortunately, the speed, effort and distance travelled fields were not well populated for these surveys. Therefore, missing values for these fields were filled in with the mean values for the survey year. This resulted in the majority of the tows having distances towed near 3 km, which was the expected result given the design specification of ½ hour tows at an approximate speed of 6 km/h (about 3.2 knots).

Table B.2. Number of tows in GIG and in all other areas (Other) by survey year and vessel conducting the survey for the 12 historical (1965 to 1995) surveys. Survey years in grey were not used in the assessment

Survey	GB Reed		Southward Ho		Eastward Ho		Ocean Selector		Frosti	
Year	Other	GIG	Other	GIG	Other	GIG	Other	GIG	Other	GIG
1965	76	8	-	-	-	-	-	-	-	-
1966	49	15	-	-	-	-	-	-	-	-
1967	17	33	-	-	-	-	-	-	-	-
1969	3	32	-	-	-	-	-	-	-	-
1971	3	36	-	-	-	-	-	-	-	-
1973	13	33	-	-	-	-	-	-	-	-
1976	23	33	-	-	-	-	-	-	-	-
1977	15	47	-	-	-	-	-	-	-	-
1979	-	-	20	59	-	-	-	-	-	-
1984	19	42	-	-	15	27	-	-	-	-
1994	-	-	-	-	-	-	-	69	-	-
1995	-	-	-	-	-	-	2	55	1	57

Table B.3. Total number of tows by 20 fathom depth interval (in metres) in GIG and in all other areas (Other) by survey year for the 12 historical (1965 to 1995) surveys. Survey years in grey were not used in the assessment. Some of the tows in the GIG portion of the table have usability codes other than 0,1,2, or 6.

Survey year	20 fathom depth interval (m)									Total Tows
	66-146	147-183	184-219	220-256	257-292	293-329	330-366	367-402	440-549	
Areas other than GIG										
1965	3	15	26	17	6	6	1	1	1	76
1966	3	11	18	8	2	1	3	2	1	49
1967	1	-	6	1	2	1	1	4	-	16
1969	-	1	-	1	-	1	-	-	-	3
1971	-	-	-	-	-	-	-	-	-	-
1973	-	-	4	3	2	2	2	-	-	13
1976	-	-	4	4	4	4	4	-	-	20
1977	-	-	3	2	2	3	2	-	-	12
1979	11	2	1	5	1	-	-	-	-	20
1984	-	-	4	10	7	7	6	-	-	34
1994	-	-	-	-	-	-	-	-	-	-
1995	-	-	-	-	-	-	-	-	-	-
GIG										
1965	-	2	4	1	1	-	-	-	-	8
1966	3	2	3	5	2	-	-	-	-	15
1967	1	6	11	6	10	-	-	-	-	34
1969	-	9	11	6	6	-	-	-	-	32
1971	-	5	15	9	10	-	-	-	-	39
1973	-	7	11	7	8	-	-	-	-	33
1976	-	7	15	8	6	-	-	-	-	36
1977	1	12	14	14	9	-	-	-	-	50
1979	23	12	18	6	-	-	-	-	-	59
1984	-	13	25	17	13	1	-	-	-	69
1994	-	15	18	20	18	-	-	-	-	71
1995	2	23	47	22	15	6	-	-	-	115

Table B.4. Number of tows available by survey year and depth stratum for the analysis of the historical GIG trawl survey series. Survey years in grey were not used in the base case data set.

Survey Year	Depth stratum			Total	Start Date	End Date
	120-183 m (70–100 fm)	184-218 m (100–120 fm)	219-300 m (120–160 fm)			
1967	7	11	15	33	07-Sep-67	03-Oct-67
1969	9	11	12	32	14-Sep-69	24-Sep-69
1971	4	15	17	36	14-Oct-71	28-Oct-71
1973	7	11	15	33	07-Sep-73	24-Sep-73
1976	7	13	13	33	09-Sep-76	26-Sep-76
1977	13	14	20	47	24-Aug-77	07-Sep-77
1984	13	23	33	69	05-Aug-84	08-Sep-84
1994	10	16	24	50	21-Jun-94	06-Jul-94
1995	22	45	45	112	11-Sep-95	22-Sep-95

Table B.5. Biomass estimates for Silvergray Rockfish from the historical Goose Island Gully trawl surveys for the years 1967 to 1994. Biomass estimates are based on three depth strata (Table B.4), assuming that the survey tows were randomly selected within these areas. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
1967	598	605	233	1,246	0.421	0.405
1969	645	649	353	1,055	0.283	0.293
1971	1,324	1,273	476	3,445	0.537	0.545
1973	1,604	1,601	307	4,711	0.635	0.621
1976	1,351	1,342	290	3,637	0.655	0.693
1977	1,742	1,719	568	3,499	0.427	0.427
1984	3,240	3,195	1,616	5,834	0.312	0.313
1994	171	172	80	337	0.379	0.386
1995	547	550	375	752	0.174	0.175

B.4.2. Results

Maps showing the locations where SGR were caught in the GIG indicate that this species is mainly found along the 200 m depth contour in all years (see Figure B.2 to Figure B.10). Catch weights for SGR were much higher and more frequent than they were in either WCVI survey, with 31 tows (of 262 positive tows) with more than 100 kg of SGR. Although this species tends to be aggregated, only 4 tows were greater than 700 kg and only one greater than 1 t. SGR were mainly taken at depths from 154 to 27 m (5% and 95% quantiles of the starting depth empirical distribution), with the minimum and maximum observed depths at 89 and 282 m respectively (Figure B.11).

Estimated biomass levels in the GIG for Silvergray Rockfish from the historical GIG trawl surveys generally increased up to the 1984 survey (Figure B.12; Table B.5). The two GIG surveys which operated in the 1990s had very low SGR biomass indices (Table B.5). Survey relative errors are variable for this species in this survey, ranging from a low of 0.17 in 1995 to 0.82 (Table B.5). The proportion of tows which caught SGR is variable, ranging from a low of 17% in 1977 to a high of 0.65 in 1976 (Figure B.13). Overall, 259 tows from a total 444 valid tows (58%) contained SGR. This is a higher incidence of SGR than was seen in the South aerial stratum of the modern Queen Charlotte Sound synoptic survey, which includes the GIG (see Section B.7).

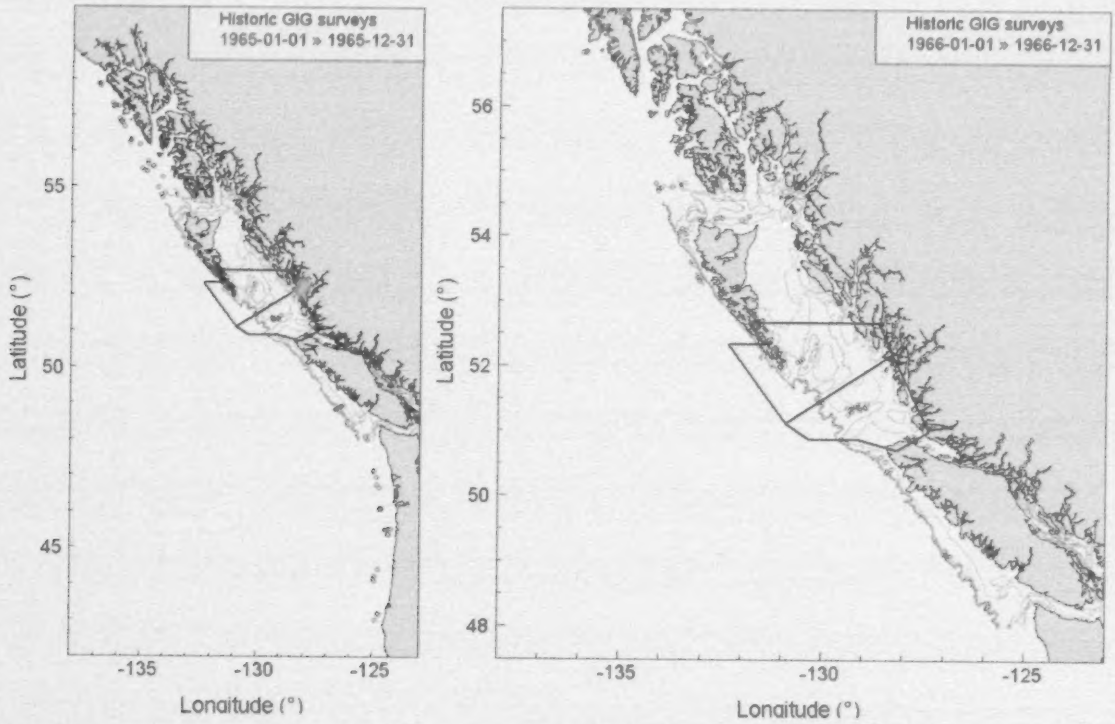

Figure B.1. Extent of the first two GB Reed surveys: [left panel] tow locations for the 1965 survey; [right panel] tow locations for the 1966 survey.

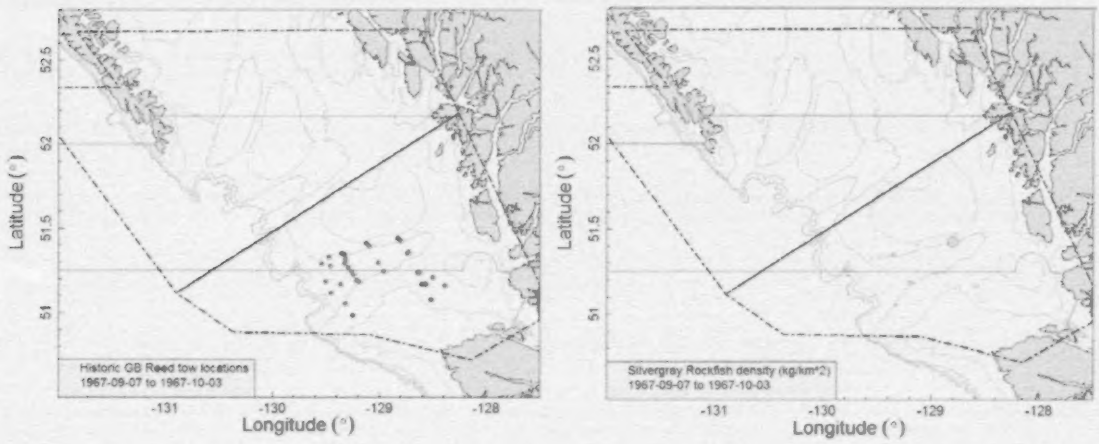

Figure B.2. Valid tow locations and density plots for the historic 1967 Goose Island Gully (GIG) survey. Tow locations are colour-coded by depth range: black=120–183m; red=184-218m; grey=219-300m. Circle sizes in the right-hand density plot scaled across all years (1967, 1969, 1971, 1973, 1976, 1977, 1984, 1994, and 1995), with the largest circle = 10,234 kg/km^2 in 1976. Black boundary lines show the extent of the modern Queen Charlotte Sound synoptic survey and the red solid lines indicate the boundaries between PMFC areas 5A, 5B and 5C.

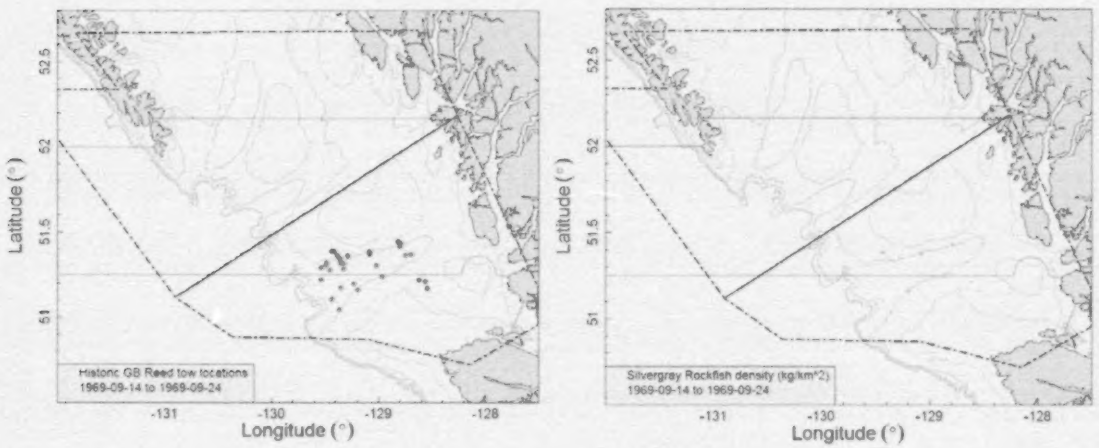

Figure B.3. Tow locations and density plots for the historic 1969 Goose Island Gully (GIG) survey (see Figure B.2 caption).

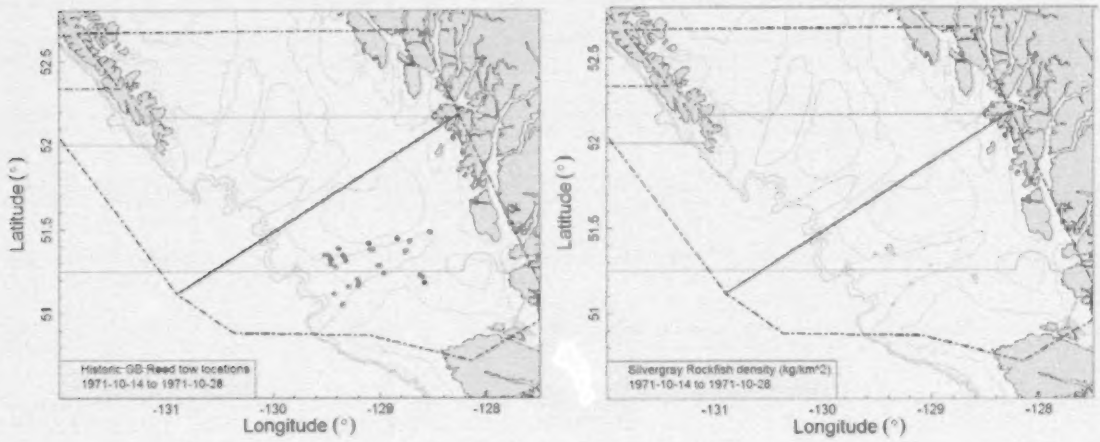

Figure B.4. Tow locations and density plots for the historic 1971 Goose Island Gully (GIG) survey (see Figure B.2 caption).

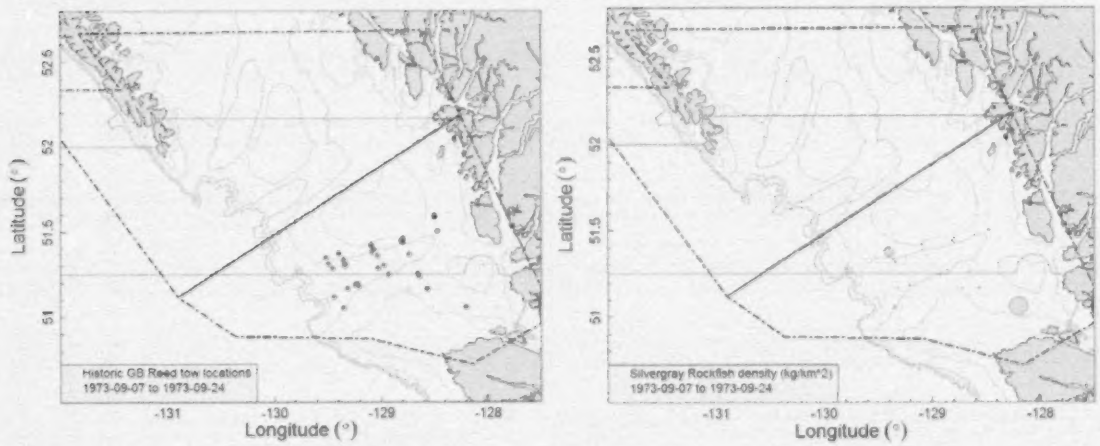

Figure B.5. Tow locations and density plots for the historic 1973 Goose Island Gully (GIG) survey (see Figure B.2 caption).

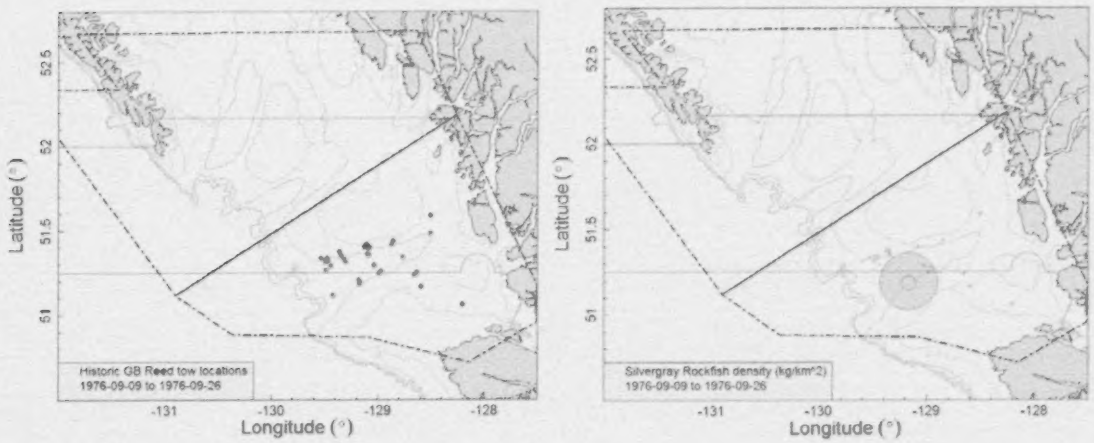

Figure B.6. Tow locations and density plots for the historic 1976 Goose Island Gully (GIG) survey (see Figure B.2 caption).

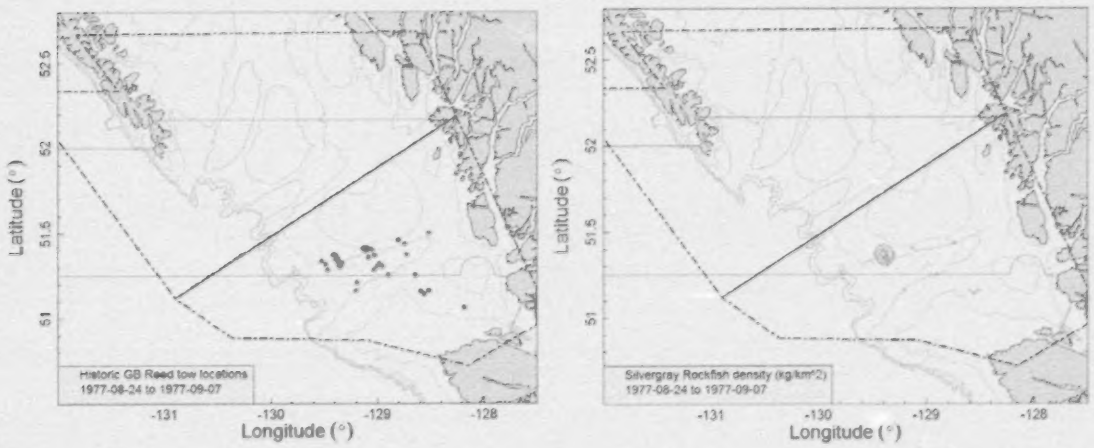

Figure B.7. Tow locations and density plots for the historic 1977 Goose Island Gully (GIG) survey (see Figure B.2 caption).

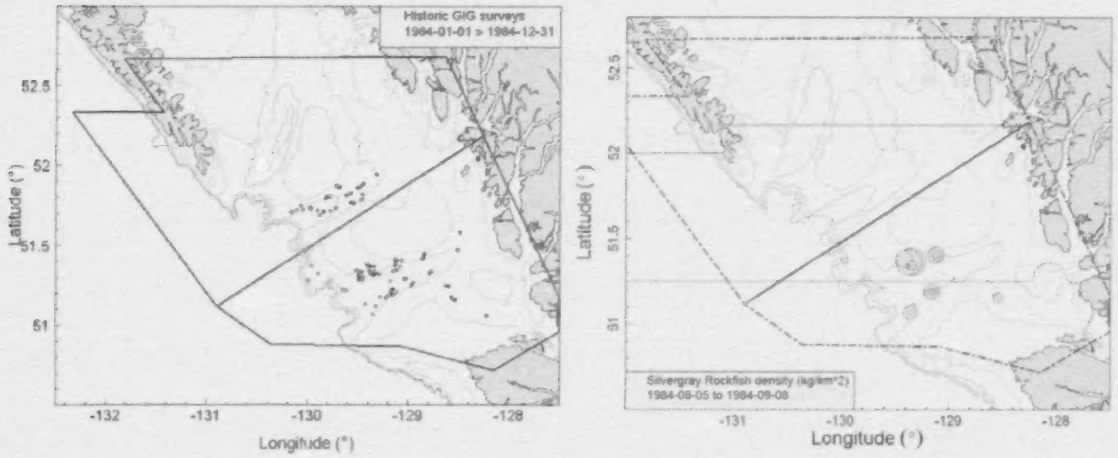

Figure B.8. [left panel]: Tow location colours indicate the vessel fishing rather than depth: black=GB Reed; red=Eastward Ho. Additional locations fished by vessel in Mitchell Gully are also shown; [right panel]: density plot for the historic 1984 Goose Island Gully (GIG) survey (see Figure B.2 caption).

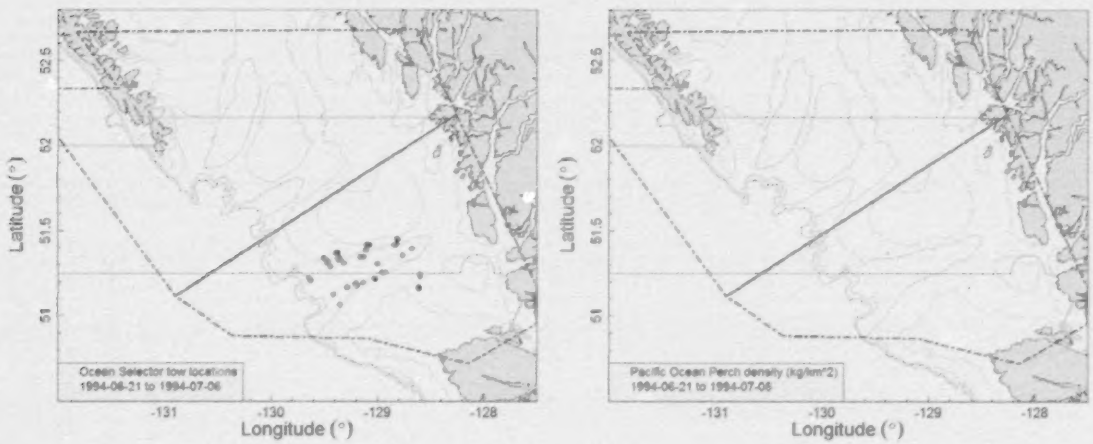

Figure B.9. Tow locations and density plots for the historic 1994 Goose Island Gully (GIG) survey (see Figure B.2 caption).

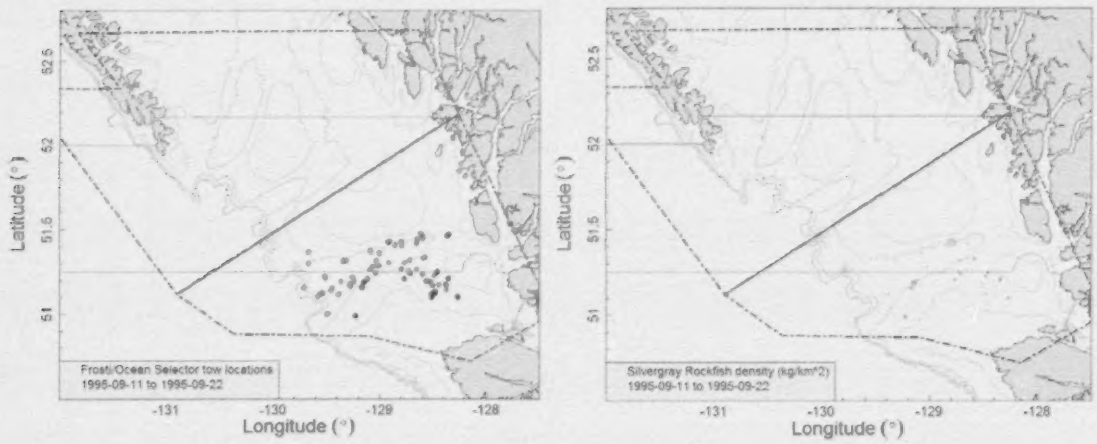

Figure B.10. Tow locations and density plots for the historic 1995 Goose Island Gully (GIG) survey(see Figure B.2 caption).

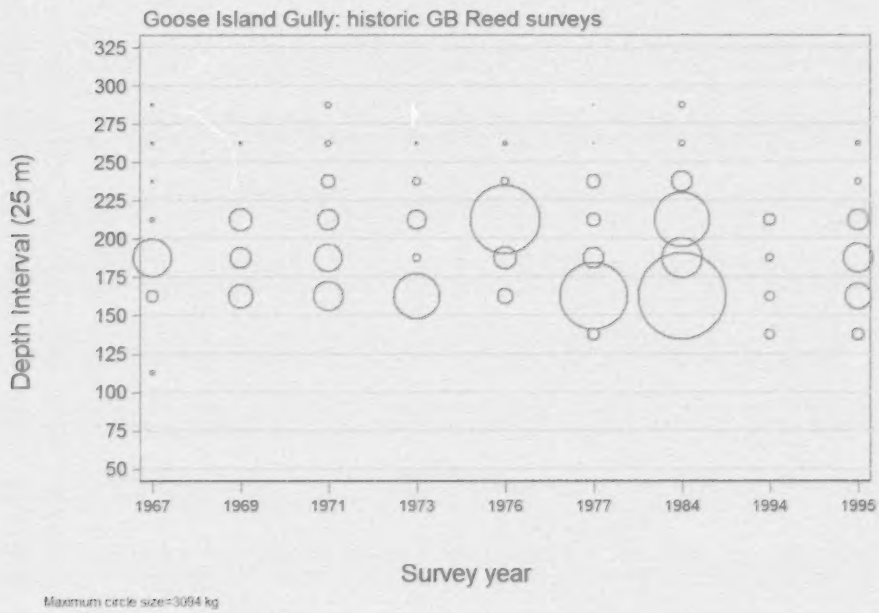

Figure B.11. Distribution of observed catch weights of Silvergray Rockfish (SGR) for the historic Goose Island Gully (GIG) surveys (Table B.4) by survey year and 25 m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the panel are scaled to the maximum value (3,094 kg) in the 150–175 m interval in 1984. The 1% and 99% quantiles for the SGR empirical start of tow depth distribution= 146 m and 278 m respectively.

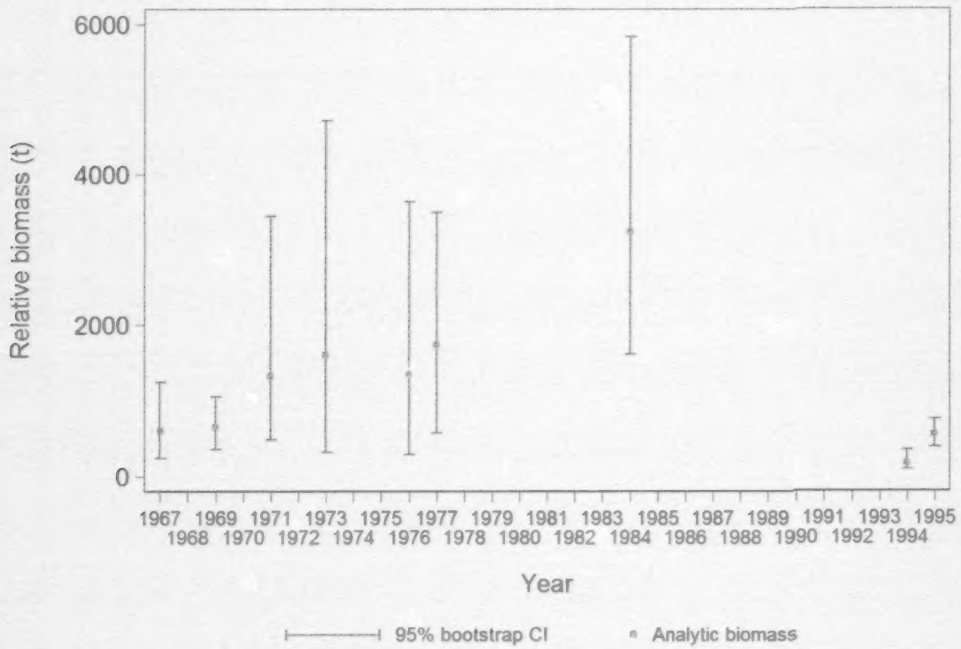

Figure B.12. Plot of biomass estimates for the SGR historic Goose Island Gully (GIG) surveys: 1967 to 1995 (values provided in Table B.5). Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

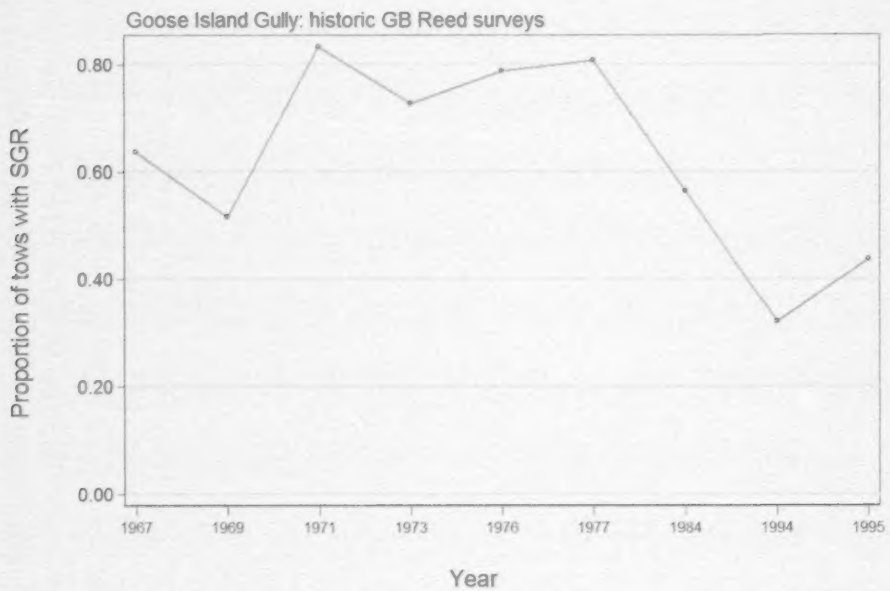

Figure B.13. Proportion of tows by year which contain SGR from the historic Goose Island Gully (GIG) surveys: 1967 to 1995.

B.5. NMFS TRIENNIAL TRAWL SURVEY

B.5.1. Data selection

Tow-by-tow data from the US National Marine Fisheries Service (NMFS) triennial survey covering the Vancouver INPFC (International North Pacific Fisheries Commission) region were provided by (Mark Wilkins, NMFS, pers. comm.) for the seven years that the survey worked in BC waters (Table B.6; 1980: Figure B.14; 1983: Figure B.15; 1989: Figure B.16; 1992: Figure B.17; 1995: Figure B.18; 1998: Figure B.19; 2001: Figure B.20). These tows were assigned to strata by the NMFS, but the size and definition of these strata have changed over the life of the survey (Table B.7). The NMFS survey database also identified in which country the tow was located. This information was plotted and checked against the accepted Canada/USA marine boundary: all tows appeared to be appropriately located with respect to country, based on the tow start position (Figure B.14 to Figure B.20). The NMFS designations were accepted for tows located near the marine border.

All usable tows had an associated median net width (with 1-99% quantiles) of 13.4 (11.3-15.7) m and median distance travelled of 2.8 (1.4-3.5) km, allowing for the calculation of the area swept by each tow. Biomass indices and the associated analytical CVs for Silvergray Rockfish were calculated for the total Vancouver INPFC region and for each of the Canadian- and US-Vancouver sub-regions, using appropriate area estimates for each stratum and year (Table B.7). Strata that were not surveyed consistently in all seven years of the survey were dropped from the analysis (Table B.6; Table B.7), allowing the remaining data to provide a comparable set of data for each year (Table B.8).

Table B.6. Number of tows by stratum and by survey year for the NFMS triennial survey. Strata coloured grey have been excluded from the analysis due to incomplete coverage across the seven survey years or were from locations outside the Vancouver INPFC area (Table B.7).

Stratum	1980		1983		1989		1992		1995		1998		2001	
No.	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US	CDN	US
10	-	17	-	7	-	-	-	-	-	-	-	-	-	-
11	48	-	-	39	-	-	-	-	-	-	-	-	-	-
12	-	-	38	-	-	-	-	-	-	-	-	-	-	-
17N	-	-	-	-	-	8	-	9	-	8	-	8	-	8
17S	-	-	-	-	-	27	-	27	-	25	-	26	-	25
18N	-	-	-	-	1	-	1	-	-	-	-	-	-	-
18S	-	-	-	-	-	32	-	23	-	12	-	20	-	14
19N	-	-	-	-	58	-	53	-	55	-	48	-	33	-
19S	-	-	-	-	-	4	-	6	-	3	-	3	-	3
27N	-	-	-	-	-	2	-	1	-	2	-	2	-	2
27S	-	-	-	-	-	5	-	2	-	3	-	4	-	5
28N	-	-	-	-	1		1	-	2	-	1	-	-	-
28S	-	-	-	-	-	6	-	9	-	7	-	6	-	7
29N	-	-	-	-	7	-	6	-	7	-	6	-	3	-
29S	-	-	-	-	-	3	-	2	-	3	-	3	-	3
30	-	4	-	2	-	-	-	-	-	-	-	-	-	-
31	7	-	-	11	-	-	-	-	-	-	-	-	-	-
32	-	-	5	-	-	-	-	-	-	-	-	-	-	-
37N	-	-	-	-	-	-	-	-	-	1	-	1	-	1
37S	-	-	-	-	-	-	-	-	-	2	-	1	-	1
38N	-	-	-	-	-	-	-	-	1	-	-	-	-	-
38S	-	-	-	-	-	-	-	-		2	-	-	-	3
39	-	-	-	-	-	-	-	-	6	-	4	-	2	-
50	-	5	-	1	-	-	-	-	-	-	-	-	-	-
51	4	-	-	10	-	-	-	-	-	-	-	-	-	-
52	-	-	4	-	-	-	-	-	-	-	-	-	-	-
Total	**59**	**26**	**47**	**70**	**67**	**87**	**61**	**79**	**71**	**68**	**59**	**74**	**38**	**72**

Table B.7. Stratum definitions by year used in the NMFS triennial survey to separate the survey results by country and by INPFC area. Stratum definitions in grey are those strata which have been excluded from the final analysis due to incomplete coverage across the seven survey years or because the locations were outside the Vancouver INPFC area.

Year	Stratum No.	Area (km^2)	Start	End	Country	INPFC area	Depth range
1980	10	3537	47°30	US-Can Border	US	Vancouver	55-183 m
1980	11	6572	US-Can Border	49°15	CDN	Vancouver	55-183 m
1980	30	443	47°30	US-Can Border	US	Vancouver	184-219 m
1980	31	325	US-Can Border	49°15	CDN	Vancouver	184-219 m
1980	50	758	47°30	US-Can Border	US	Vancouver	220-366 m
1980	51	503	US-Can Border	49°15	CDN	Vancouver	220-366 m
1983	10	1307	47°30	47°55	US	Vancouver	55-183 m
1983	11	2230	47°55	US-Can Border	US	Vancouver	55-183 m
1983	12	6572	US-Can Border	49°15	CDN	Vancouver	55-183 m
1983	30	66	47°30	47°55	US	Vancouver	184-219 m
1983	31	377	47°55	US-Can Border	US	Vancouver	184-219 m
1983	32	325	US-Can Border	49°15	CDN	Vancouver	184-219 m
1983	50	127	47°30	47°55	US	Vancouver	220-366 m
1983	51	631	47°55	US-Can Border	US	Vancouver	220-366 m
1983	52	503	US-Can Border	49 °15	CDN	Vancouver	220-366 m
1989&after	17N	1033	47°30	47°50	US	Vancouver	55-183 m
1989&after	17S	3378	46°30	47°30	US	Columbia	55-183 m
1989&after	18N	159	47°50	48°20	CDN	Vancouver	55-183 m
1989&after	18S	2123	47°50	48°20	US	Vancouver	55-183 m
1989&after	19N	8224	48°20	49°40	CDN	Vancouver	55-183 m
1989&after	19S	363	48°20	49°40	US	Vancouver	55-183 m
1989&after	27N	125	47°30	47°50	US	Vancouver	184-366 m
1989&after	27S	412	46°30	47°30	US	Columbia	184-366 m
1989&after	28N	88	47°50	48°20	CDN	Vancouver	184-366 m
1989&after	28S	787	47°50	48°20	US	Vancouver	184-366 m
1989&after	29N	942	48°20	49°40	CDN	Vancouver	184-366 m
1989&after	29S	270	48°20	49°40	US	Vancouver	184-366 m
1995&after	37N	102	47°30	47°50	US	Vancouver	367-500 m
1995&after	37S	218	46°30	47°30	US	Columbia	367-500 m
1995&after	38N	66	47°50	48°20	CDN	Vancouver	367-500 m
1995&after	38S	175	47°50	48°20	US	Vancouver	367-500 m

Table B.8. Number of usable tows performed and area surveyed in the INPFC Vancouver region separated by the international border between Canada and the United States. Strata 18N, 28N, 37, 38 and 39 (Table B.7) were dropped from this analysis as they were not consistently conducted over the survey period. All strata occurring in the Columbia INPFC region (17S and 27S; Table B.7) were also dropped.

Survey year	Number of tows			Area surveyed (km^2)		
	CDN waters	US waters	Total	CDN waters	US waters	Total
1980	59	26	85	7,399	4,738	12,137
1983	47	70	117	7,399	4,738	12,137
1989	65	55	120	9,166	4,699	13,865
1992	59	50	109	9,166	4,699	13,865
1995	62	35	97	9,166	4,699	13,865
1998	54	42	96	9,166	4,699	13,865
2001	36	37	73	9,166	4,699	13,865
Total	382	315	697	–	–	–

The stratum definitions used in the 1980 and 1983 surveys were different than those used in subsequent surveys, particularly in Canadian waters (Table B.8). Therefore, the 1980 and 1983

indices were scaled up by the ratio (9166 km^2 / 7399 km^2 = 1.24) of the total stratum areas relative to the 1989 and later surveys so that the coverage from the first two surveys would be comparable to the surveys conducted from 1989 onwards. The tow density was much higher in US waters although the overall number of tows was approximately the same for each country (Table B.8). This occurs because the size of the total area fished in the INPFC Vancouver area was about twice as large in Canadian waters than in US waters (Table B.8). Note that the northern extension of the survey has varied from year to year (Figure B.14 to Figure B.20), but this difference has been compensated for by using a constant survey area for all years and assuming that catch rates in the unsampled areas were the same as in the sampled area.

B.5.2. Methods

The data were analysed using the equations in Section B.2. When calculating the variance for this survey, it was assumed that the variance and CPUE within any stratum was equal, even for strata that were split by the Canada/USA border. The total biomass $\left(B_{y_i}\right)$ within a stratum that straddled the border was split between the two countries $\left(B_{y_{ic}}\right)$ by the ratio of the relative area within each country:

Eq. B.7
$$B_{y_{ic}} = B_{y_i} \frac{A_{y_{ic}}}{A_{y_i}},$$

where $A_{y_{ic}}$ = area (km^2) within country *c* in year *y* and stratum *i*.

The variance $V_{y_{ic}}$ for that part of stratum *i* within country *c* was calculated as being in proportion to the ratio of the square of the area within each country *c* relative to the total area of stratum *i*. This assumption resulted in the CVs within each country stratum being the same as the CV in the entire stratum:

Eq. B.8
$$V_{y_{ic}} = V_{y_i} \frac{A^2_{y_{ic}}}{A^2_{y_i}}.$$

The partial variance $V_{y_{ic}}$ for country *c* was used in Eq. B.5 instead of the total variance in the stratum $V_{y_{ic}}$ when calculating the variance for the total biomass in Canadian or American waters.

CVs were calculated as in Eq. B.6.

The biomass estimates Eq. B.4 and the associated standard errors were adjusted to a constant area covered using the ratios of area surveyed provided in Table B.8. This was required to adjust the Canadian biomass estimates for 1980 and 1983 to account for the smaller area surveyed in those years compared to the succeeding surveys. The 1980 and 1983 biomass estimates from Canadian waters were consequently multiplied by the ratio 1.24 (= 9166 km^2 / 7399 km^2) to make them equivalent to the coverage of the surveys from 1989 onwards.

Biomass estimates were bootstrapped for 1000 random draws with replacement to obtain bias-corrected (Efron 1982) 95% confidence intervals for each year and for three area categories (total Vancouver region, Canadian-Vancouver only and US-Vancouver only) based on the distribution of biomass estimates and using the above equations.

B.5.3. Results

Silvergray Rockfish (SGR) is characterised by occasional large tows in this region along with a large number of non-productive tows and low catch tows. There were only 10 tows of the nearly 700 valid tows which held more than 100 kg of SGR, with two tows greater than 1,500 kg (one in 1980 in Canadian waters [Figure B.14] and the other in 1983 in US waters [Figure B.15]). The occasional nature of these large tows results in considerable uncertainty for these biomass estimates as evidenced by the large CVs. Coverage by depth has been consistent for all seven years of the survey after the exclusion of the deep strata that were not covered in the earlier surveys (Figure B.21). The latter plot shows that this species was mainly found between 108 and 219 m (5 and 95% quantiles of [`bottom_depth`]), with few differences in preferred depth range between years. The large tow in 1983 in US waters was made at 229 m while the large 1980 tow in Canadian waters was made at 148 m.

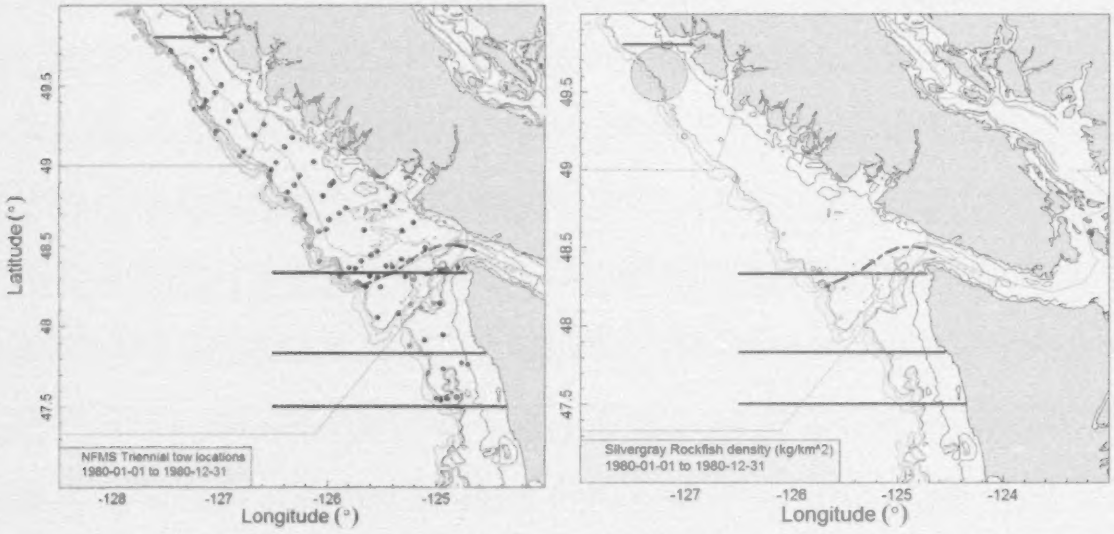

Figure B.14. [left panel]: plot of tow locations in the Vancouver INPFC region for the 1980 NMFS triennial survey in Canadian waters. Tow locations are colour-coded by depth range: black=55-183m; red=184-366m; grey=367-500m. Dashed line shows approximate position of the Canada/USA marine boundary. Horizontal lines are the stratum boundaries: 47°30', 47°50', 48°20' and 49°50'. Tows south of the 47°30' line were not included in the analysis. [right panel]: circle sizes in the density plot are scaled across all years (1980, 1983, 1989, 1992, 1995, 1998, and 2001), with the largest circle = 50,806 kg/km^2 in 1983. The red solid lines indicate the boundaries between PMFC areas 3C and 3D.

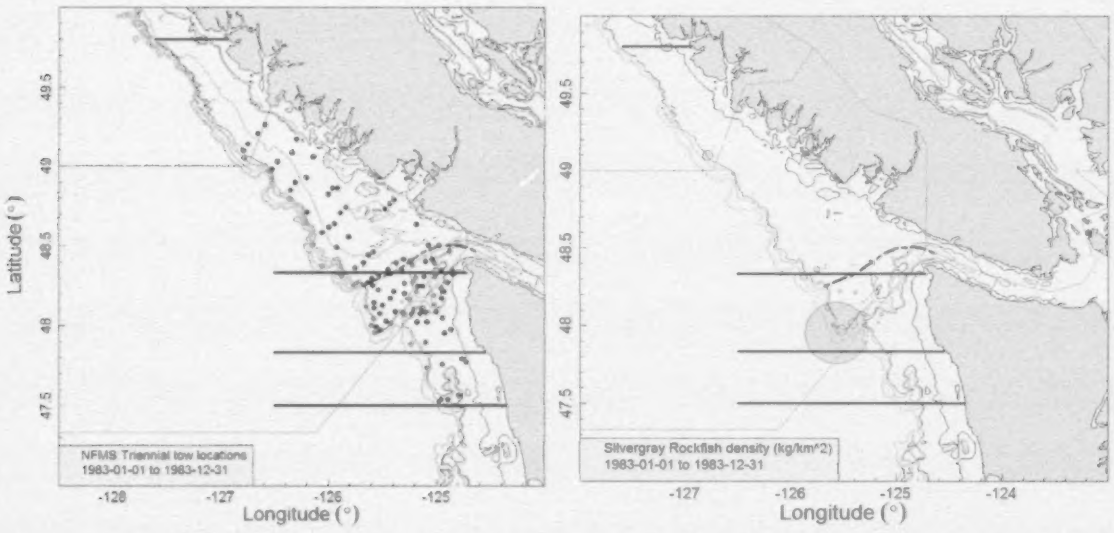

Figure B.15. Tow locations and density plots for the 1983 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

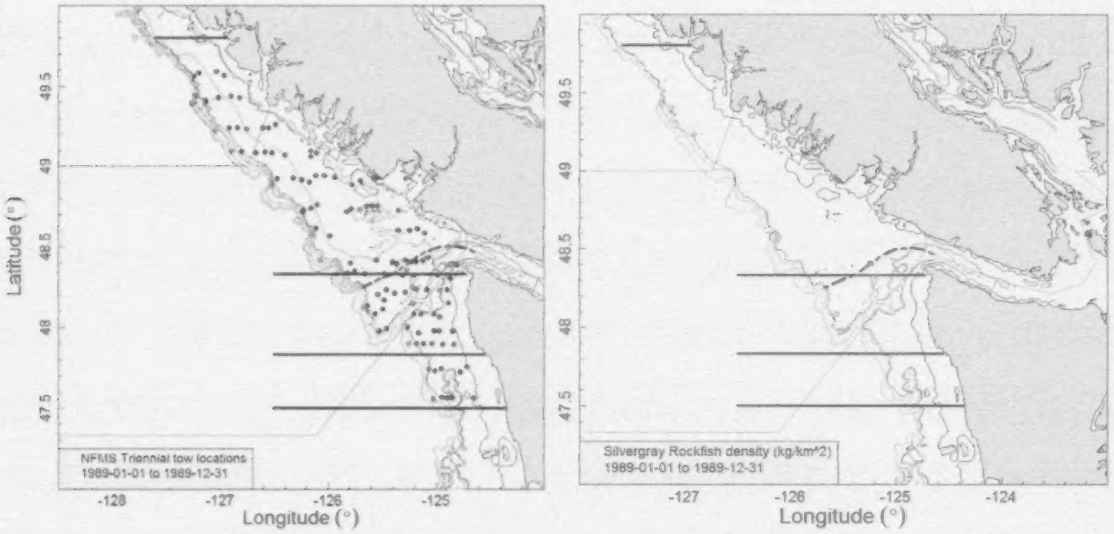

Figure B.16. Tow locations and density plots for the 1989 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

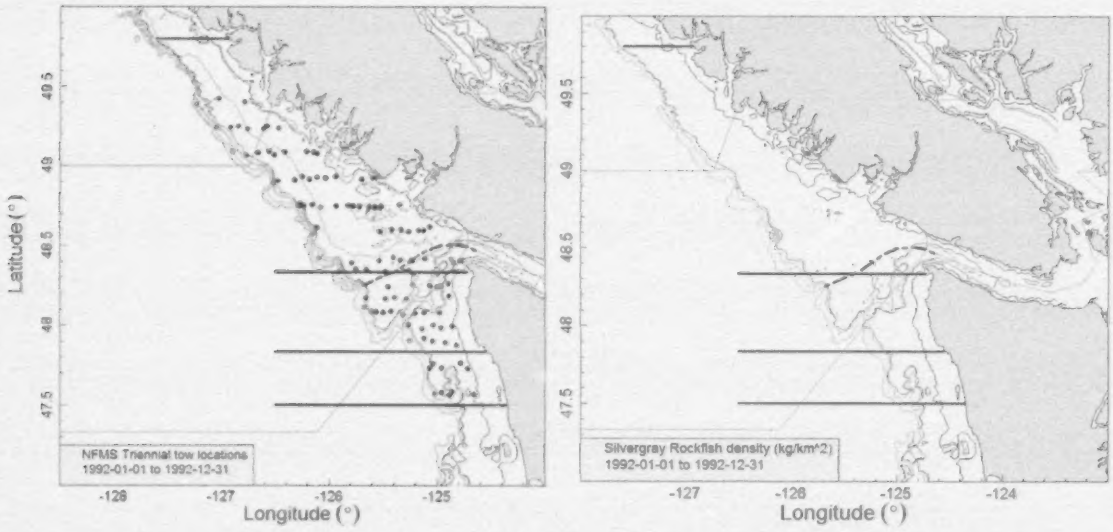

Figure B.17. Tow locations and density plots for the 1992 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

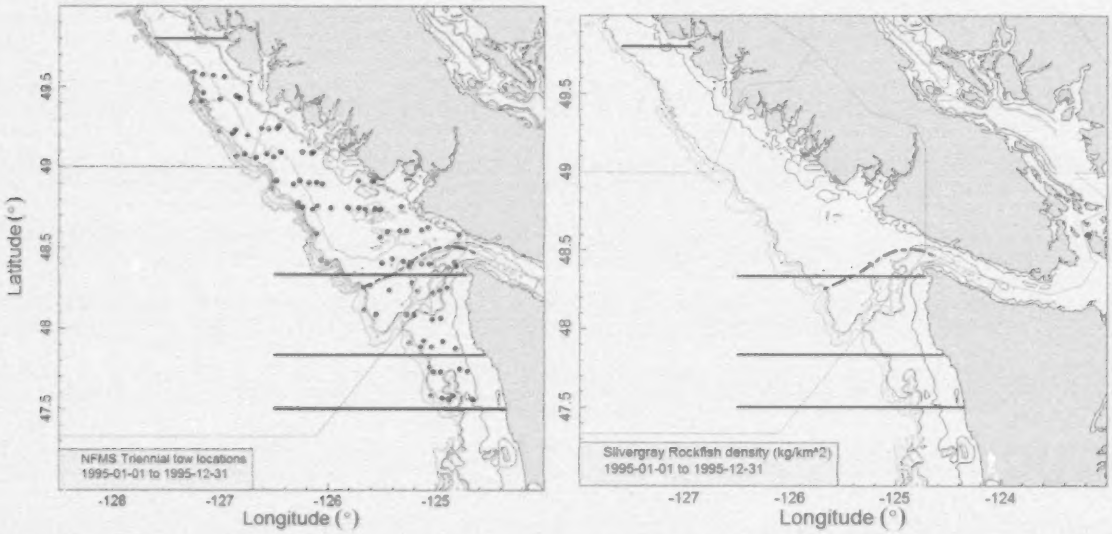

Figure B.18. Tow locations and density plots for the 1995 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

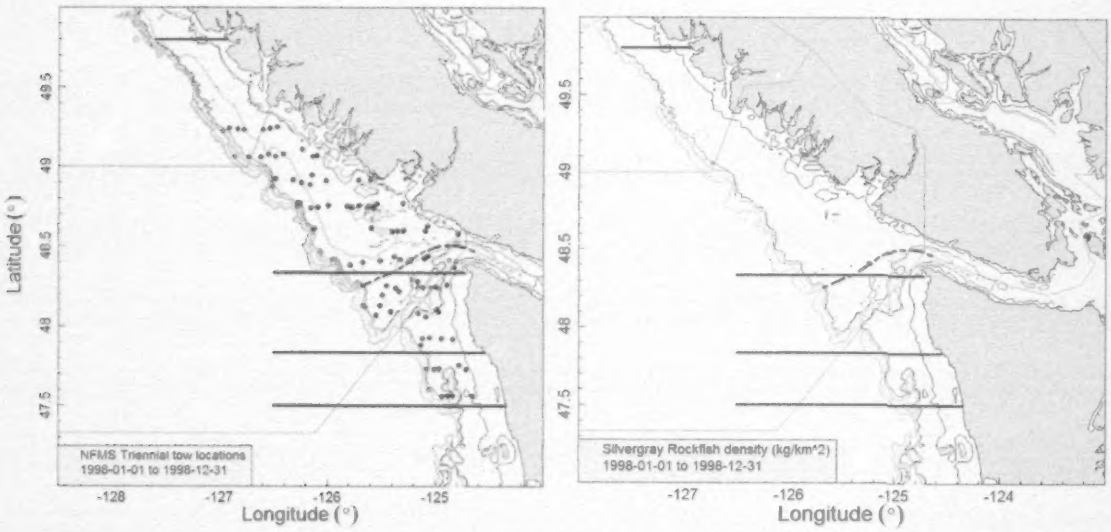

Figure B.19. Tow locations and density plots for the 1998 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

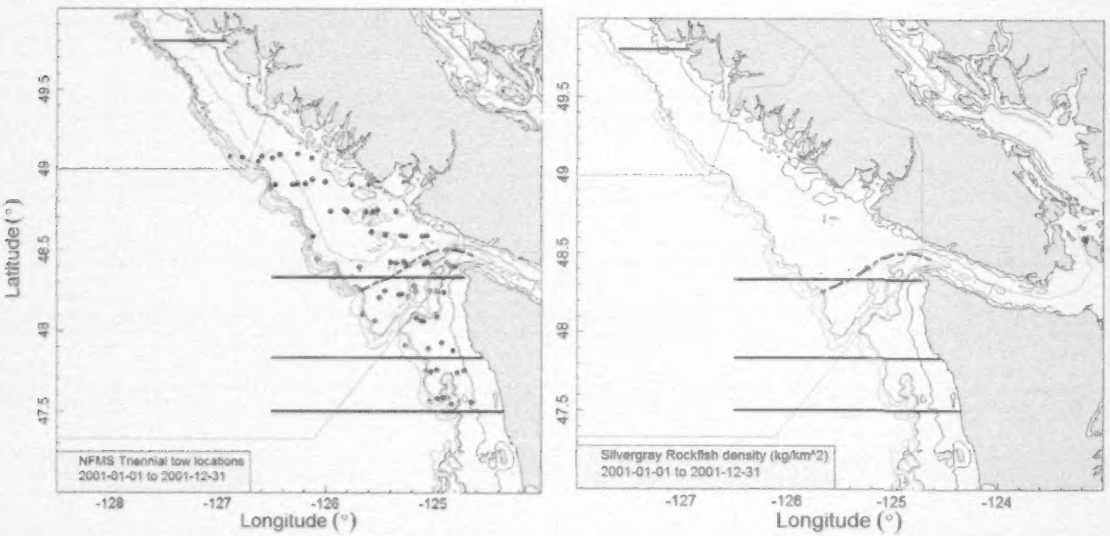

Figure B.20. Tow locations and density plots for the 2001 NMFS triennial survey in Canadian waters (see Figure B.14 caption).

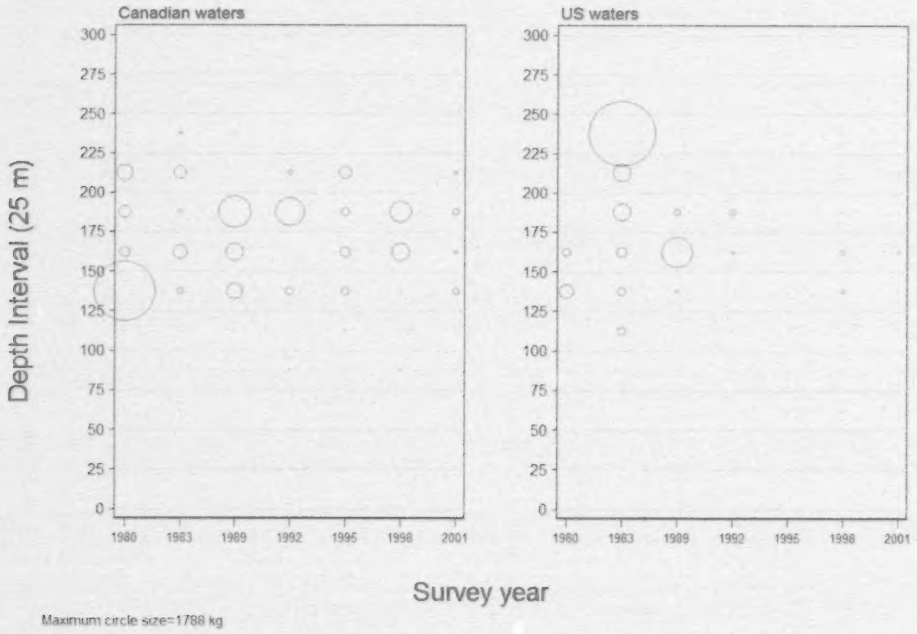

Figure B.21. Distribution of Silvergray Rockfish catch weights for each survey year summarised into 25 m depth intervals for all valid tows (Table B.7) in Canadian and US waters of the Vancouver INPFC area. Depth intervals are labelled with the mid-point of the interval.

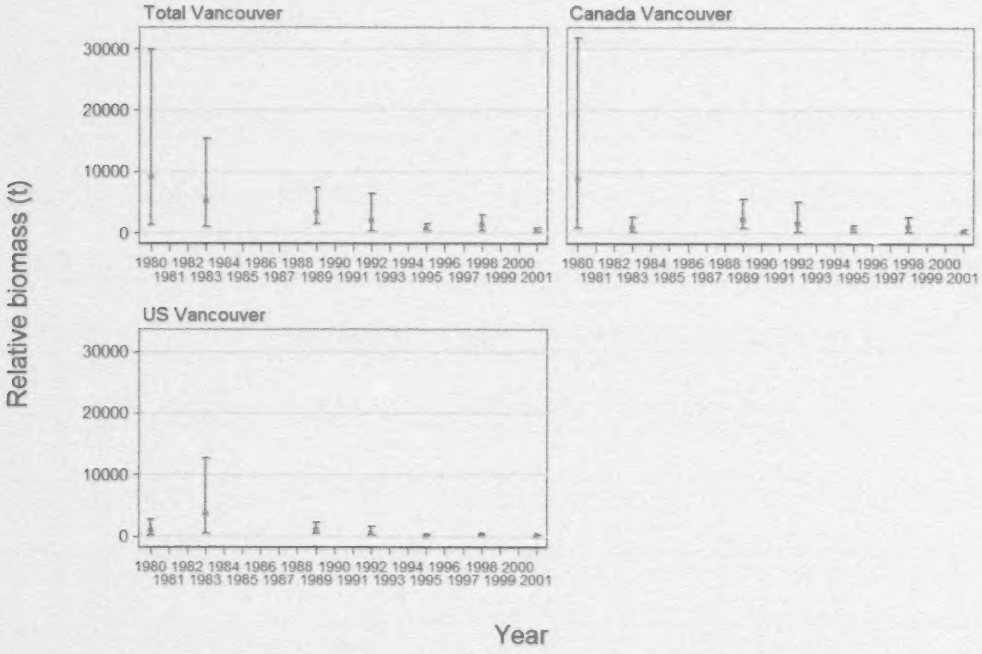

Figure B.22. Biomass estimates for three series of Silvergray Rockfish in the INPFC Vancouver region (total region, Canadian waters only, and US waters only) with 95% bias-corrected error bars estimated from 1000 bootstraps.

Table B.9. Biomass estimates for Silvergray Rockfish in the Vancouver INPFC region (total region, Canadian waters only, and US waters only) with 95% confidence bounds based on the bootstrap distribution of biomass. Bootstrap estimates are based on 1000 random draws with replacement.

Estimate series	Year	Biomass (Eq. B.4)	Mean bootstrap biomass	Lower bound biomass	Upper bound biomass	CV bootstrap	CV Analytic (Eq. B.6)
Total Vancouver	1980	9,129	9,223	1,251	29,882	0.770	0.778
	1983	5,298	5,195	1,032	15,373	0.698	0.700
	1989	3,423	3,395	1,427	7,291	0.407	0.400
	1992	2,209	2,177	303	6,317	0.708	0.751
	1995	737	740	282	1,503	0.403	0.426
	1998	1,360	1,331	348	2,951	0.491	0.485
	2001	375	381	109	797	0.447	0.460
Canada Vancouver	1980	8,829	8,970	792	31,850	0.858	0.868
	1983	1,063	1,033	230	2,613	0.557	0.563
	1989	2,393	2,390	755	5,504	0.467	0.459
	1992	1,693	1,719	169	5,035	0.735	0.763
	1995	648	654	226	1,286	0.399	0.416
	1998	1,136	1,117	232	2,577	0.525	0.519
	2001	301	307	54	658	0.520	0.531
US Vancouver	1980	864	833	147	2,649	0.681	0.684
	1983	3,779	3,714	362	12,650	0.845	0.849
	1989	1,030	1,005	343	2,238	0.443	0.436
	1992	516	458	76	1,582	0.756	0.718
	1995	90	86	18	231	0.591	0.603
	1998	224	213	80	468	0.467	0.434
	2001	74	74	24	160	0.440	0.465

Silvergray Rockfish biomass estimates in both US and Canadian waters were characterised by a declining trend from 1980 to 2001 and by a great deal of within and between-year variability (Figure B.22; Table B.9). A few large tows in the first two survey year resulted in CV estimates of greater than 80%. All surveys have imprecise biomass estimates, with CVs ranging from a minimum 40% in 1989 (total Vancouver area) to 86% for the 1992 Canadian portion (Table B.9). CVs for the sub-divided national strata tend to be higher for the same years. Note that the bootstrap estimates of CV do not include any uncertainty with respect to the ratio expansion required to make the 1980 and 1983 survey estimates comparable to the 1989 and later surveys. Therefore, it is likely that the true uncertainty for this series is even greater than estimated.

Only 129 of the 697 tows (19%) in this data set caught Silvergray Rockfish over the entire history of the survey. The proportion of tows which contained Silvergray Rockfish is lower in US waters than in Canadian waters, with the US proportions by year ranging from 7 to 24% (mean=11%) while the equivalent Canadian values are 13–36% and a mean value of 23% (Figure B.23). Both regions show a declining trend in this statistic.

The seven Triennial survey indices from the Canada Vancouver region spanning the period 1980 to 2001 were accepted as a linked series of abundance indices for use in the stock assessment model (described in Appendix D).

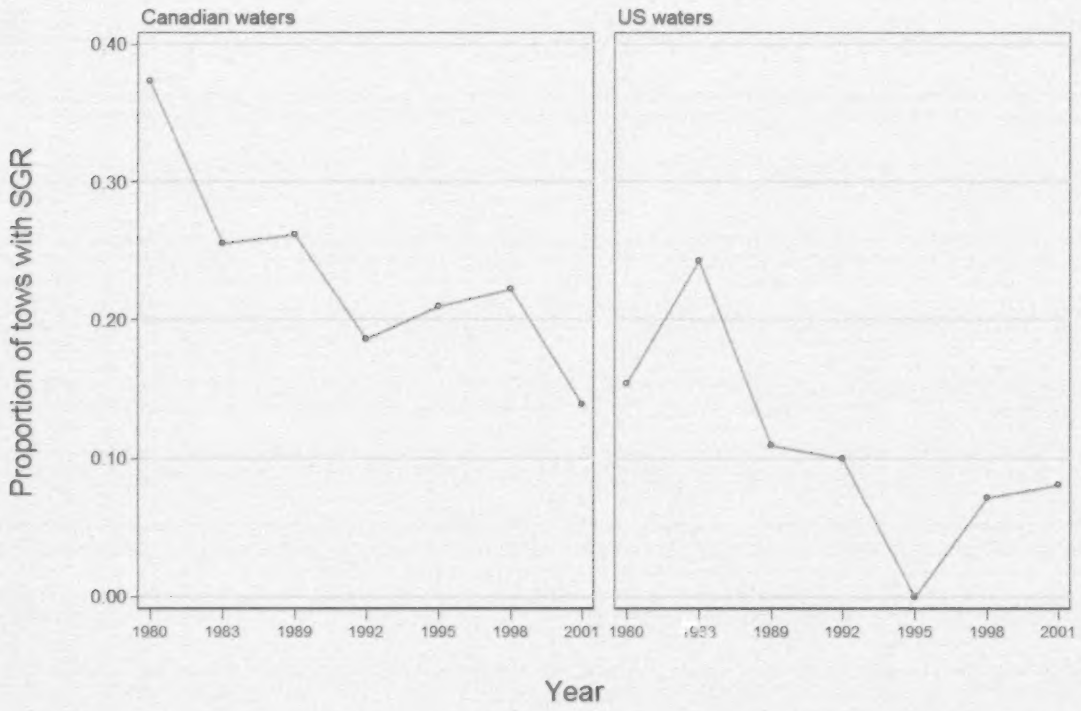

Figure B.23. Proportion of tows with Silvergray Rockfish by year for the Vancouver INPFC region (Canadian and US waters).

B.6. HECATE STRAIT SYNOPTIC SURVEY

B.6.1. Data selection

This survey has been conducted in five alternating years over the period 2005 to 2013 in Hecate Strait (HS) between Moresby and Graham Islands and the mainland and in Dixon Entrance at the top of Graham Island (all valid tow starting positions by survey year are shown in Figure B.24 to Figure B.28). This survey treats the full spatial coverage as a single aerial stratum divided into four depth strata: 10–70 m; 70–130 m; 130–220 m; and 220–500 m (Table B.10).

A doorspread density value (Eq. B.3) was generated for each tow based on the catch of Silvergray Rockfish (SGR) from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field is used preferentially for the variable D_{yij} in Eq. B.3. A calculated value ([`vessel speed`] X [`tow duration`]) can be used for this variable if [`distance travelled`] is missing, but there were no instances of this occurring in the 5 trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (217 values over all years: Table B.11).

Table B.10. Number of usable tows for biomass estimation by year and depth stratum for the Hecate Strait synoptic survey over the period 2005 to 2013. Also shown is the area of each depth stratum and the vessel conducting the survey by survey year.

Year	Vessel	Depth stratum				Total tows
		10-70	70-130	130-220	220-500	
2005	Frosti	80	88	26	9	203
2007	W.E. Ricker	48	43	36	7	134
2009	W.E. Ricker	53	43	48	12	156
2011	W.E. Ricker	71	51	50	14	186
2013	W.E. Ricker	74	42	43	16	175
Area (km^2)		5,958	3,011	2,432	1,858	13,259[1]

[1] total area for survey

Table B.11. Number of missing doorspread values by year for the Hecate Strait synoptic survey over the period 2005 to 2013 as well as showing the number of available doorspread observations and the mean doorspread value for the survey year.

Year	Number tows with missing doorspread[1]	Number tows with doorspread observations[2]	Mean doorspread (m) used for tows with missing values[2]
2005	7	217	64.4
2007	98	37	59.0
2009	93	70	54.0
2011	13	186	54.8
2013	6	176	51.7
Total	217	686	57.2

[1] valid biomass estimation tows only

[2] includes tows not used for biomass estimation

Table B.12. Biomass estimates for Silvergray Rockfish from the Hecate Strait synoptic trawl survey for the survey years 2005 to 2013. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2005	425	425	266	636	0.225	0.236
2007	262	261	163	385	0.216	0.216
2009	600	597	367	965	0.245	0.235
2011	610	614	332	946	0.256	0.258
2013	353	350	235	543	0.215	0.219

B.6.2. Results

Catch densities of SGR from this survey were highest in waters immediately north of Graham Island and in the upper reaches of Moresby Gully in the southern part of Hecate Strait (Figure B.24 to Figure B.28). SGR were mainly taken at depths from 72 to 234 m (5% and 95% quantiles of the starting depth empirical distribution), but there were sporadic observations at depths to just over 260 m and down to about 20 m (Figure B.29).

Estimated SGR doorspread biomass from this trawl survey showed no overall trend over the entire period 2005 to 2013, with the highest estimates recorded in 2009 and 2011 and low estimates in 2007 and 2013 (Table B.12; Figure B.30). The estimated relative errors were reasonable, ranging from 22 to 26% (Table B.12). On average, about thirty percent of the

survey tows captured SGR (ranging from 0.25 to 0.36 by year) (Figure B.31). Overall, 252 of the 854 valid survey tows contained SGR.

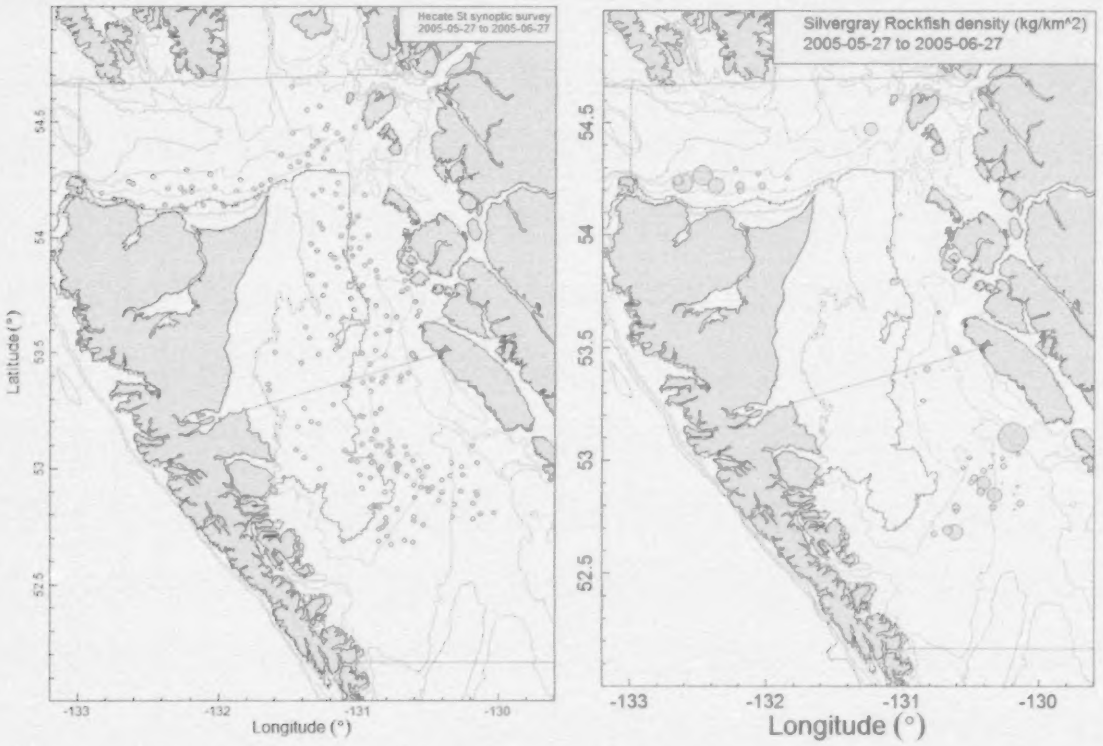

Figure B.24. Valid tow locations and density plots for the 2005 Hecate Strait synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2005, 2007, 2009, 2011, 2013), with the largest circle = 1,675 kg/km^2 in 2011. Red lines indicate boundaries for PMFC major statistical areas 5C and 5D.

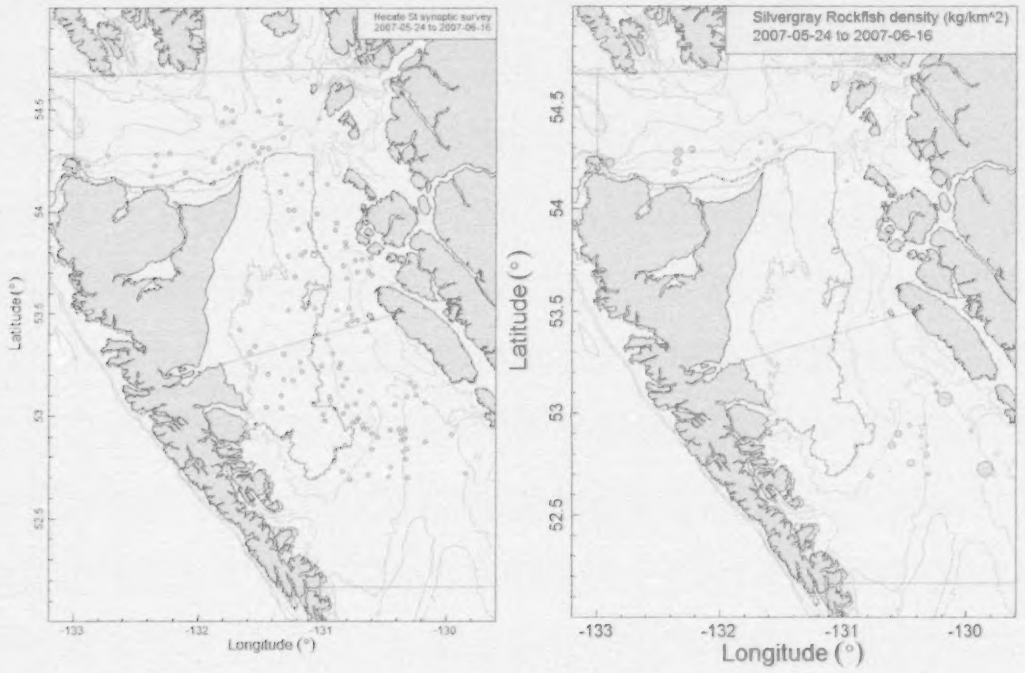

Figure B.25. Tow locations and density plots for the 2007 Hecate Strait synoptic survey (see Figure B.24 caption).

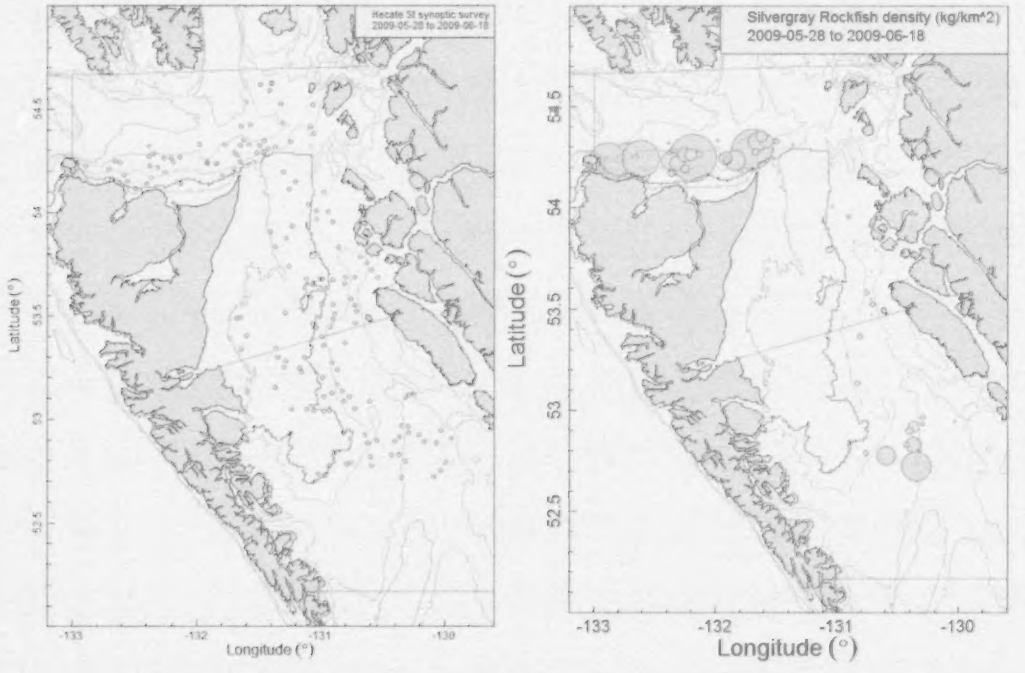

Figure B.26. Tow locations and density plots for the 2009 Hecate Strait synoptic survey (see Figure B.24 caption).

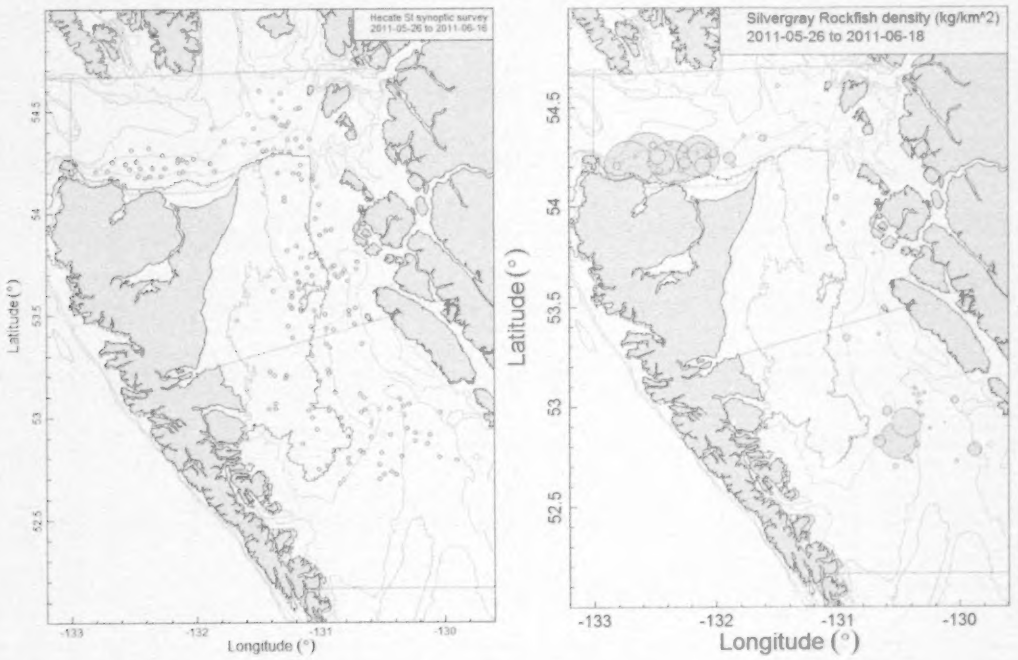

Figure B.27. Tow locations and density plots for the 2011 Hecate Strait synoptic survey (see Figure B.24 caption).

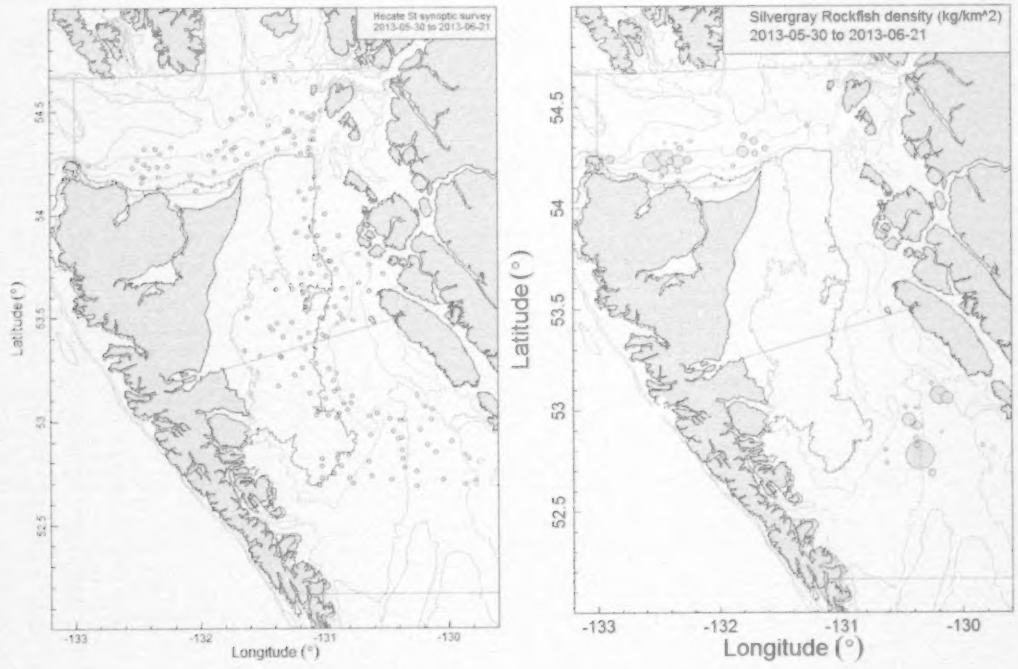

Figure B.28. Tow locations and density plots for the 2013 Hecate Strait synoptic survey (see Figure B.24 caption).

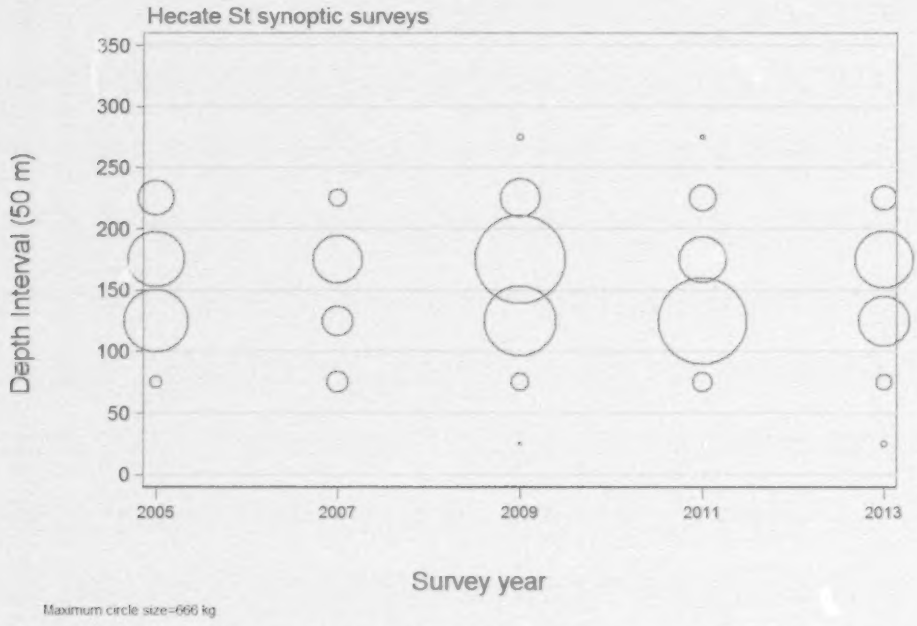

Figure B.29. Distribution of observed catch weights of Silvergray Rockfish for the Hecate Strait synoptic survey (Table B.10) by survey year and 50 m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the panel are scaled to the maximum value (666 kg) in the 150-200 m interval in 2009. The 1% and 99% quantiles for the SGR empirical start of tow depth distribution= 22 m and 291 m respectively.

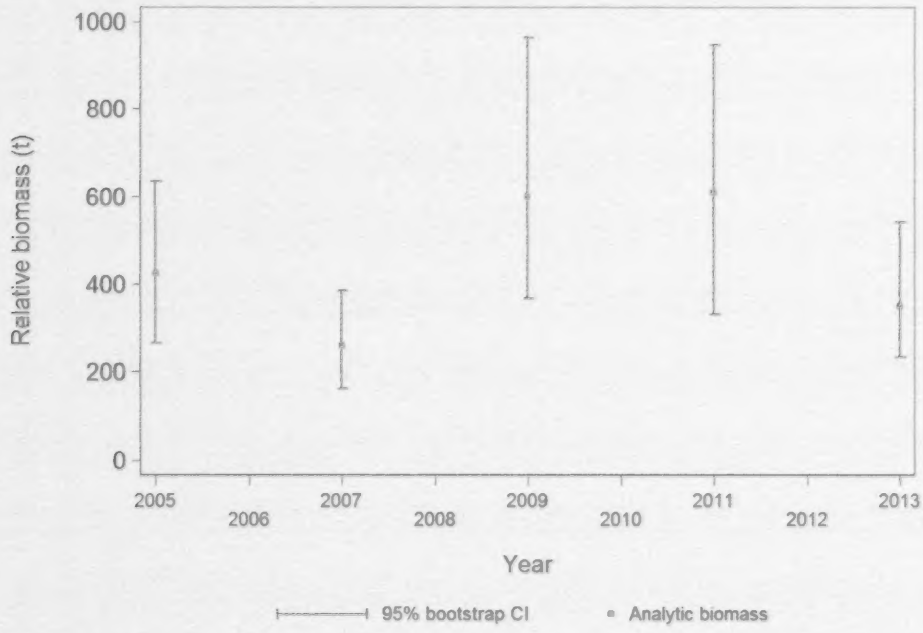

Figure B.30. Plot of biomass estimates for Silvergray Rockfish (values provided in Table B.12) from the Hecate Strait synoptic survey over the period 2005 to 2013 . Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

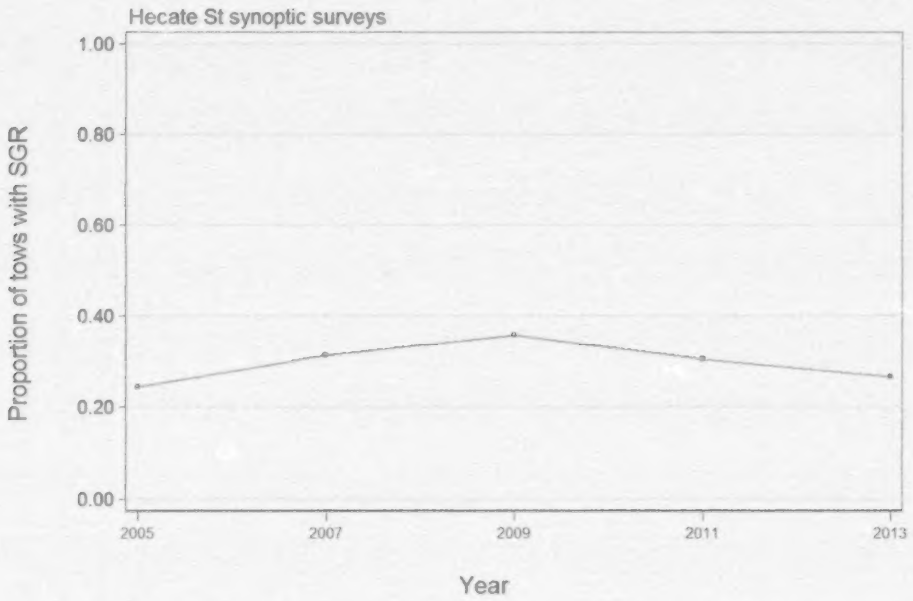

Figure B.31. Proportion of tows by year which contain Silvergray Rockfish from the Hecate Strait synoptic survey over the period 2005 to 2013.

B.7. QUEEN CHARLOTTE SOUND SYNOPTIC TRAWL SURVEY

B.7.1. Data selection

This survey has been conducted in seven years over the period 2003 to 2013 in Queen Charlotte Sound (QCS), which lies between the top of Vancouver Island and the southern portion of Moresby Island and extends into the lower part of Hecate Strait between Moresby Island and the mainland. The design divided the survey into two large aerial strata which roughly correspond to the PMFC regions 5A and 5B while also incorporating part of 5C (all valid tow starting positions are shown by survey year in Figure B.32 to Figure B.38). Each of these two areas was divided into four depth strata: 50–125 m; 125–200 m; 200–330 m; and 330–500 m (Table B.13).

A doorspread density value (Eq. B.3) was generated for each tow based on the catch of Silvergray Rockfish (SGR) from the mean doorspread for the tow and the distance travelled. [`distance travelled`] is a database field which is calculated directly from the tow track. This field is used preferentially for the variable D_{vtj} in Eq. B.3. A calculated value ([`vessel speed`] X [`tow duration`]) can be used for this variable if [`distance travelled`] is missing, but there were only two instances of this occurring in the 7 trawl surveys. Missing values for the [`doorspread`] field were filled in with the mean doorspread for the survey year (101 values over all years: Table B.14).

Table B.13. Number of usable tows for biomass estimation by year and depth stratum for the Queen Charlotte Sound synoptic survey over the period 2003 to 2013. Also shown is the area of each stratum and the vessel conducting the survey by survey year.

		South depth strata				North stratum				Total
Year	Vessel	50-125	125-200	200-330	330-500	50-125	125-200	200-330	330-500	tows
2003	Viking Storm	29	56	29	6	5	39	50	19	233
2004	Viking Storm	42	48	31	8	20	38	37	6	230
2005	Viking Storm	29	60	29	8	8	45	37	8	224
2007	Viking Storm	33	62	24	7	19	57	48	7	257
2009	Viking Storm	34	60	28	8	10	44	43	6	233
2011	Nordic Pearl	38	67	25	8	10	51	45	8	252
2013	Nordic Pearl	32	65	29	10	9	46	45	5	241
Area (km^2)		5,092	5,464	2,744	568	1,840	4,104	3,760	1,252	24,824

Table B.14. Number of missing doorspread values by year for the Queen Charlotte Sound synoptic survey over the period 2003 to 2013 as well as showing the number of available doorspread observations and the mean doorspread value for the survey year.

Year	Number tows with missing doorspread [1]	Number tows with doorspread observations [2]	Mean doorspread (m) used for tows with missing values [2]
2003	13	236	72.1
2004	8	267	72.8
2005	1	258	74.5
2007	5	262	71.8
2009	2	248	71.3
2011	30	242	67.0
2013	42	226	69.5
Total	101	1,739	71.3

[1] valid biomass estimation tows only

[2] includes tows not used for biomass estimation

Table B.15. Biomass estimates for Silvergray Rockfish from the Queen Charlotte Sound synoptic trawl survey for the survey years 2003 to 2013. Bootstrap bias corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2003	2,376	2,373	1,725	3,287	0.165	0.169
2004	3,991	4,010	2,646	5,640	0.194	0.199
2005	2,825	2,819	2,225	3,563	0.125	0.124
2007	3,657	3,668	2,510	5,547	0.208	0.212
2009	4,078	4,108	2,444	6,881	0.272	0.269
2011	3,972	3,988	2,817	5,953	0.197	0.201
2013	14,806	14,558	7,010	28,121	0.366	0.389

B.7.2. Results

Catch densities of SGR from this survey tended to be higher in the North stratum, which includes Moresby Gully and part of Mitchell Gully but this species is also present in Goose Island Gully, which is in the South stratum (Figure B.32 to Figure B.38). SGR were mainly taken at depths from 118 to 278 m (5% and 95% quantiles of the starting depth empirical distribution), but there were sporadic observations at depths up to 400 m and down to about 60 m (Figure B.39).

Estimated SGR doorspread biomass from this trawl survey showed no overall trend from 2003 to 2011, but with a strong showing in 2013 where the biomass estimate increased by more than three times over the 2011 estimate (Table B.15; Figure B.40). The estimated relative errors are variable and can be high for this species, lying between 13 and 37% (Table B.15). The proportion of tows that captured SGR was always low (between 19 and 28% in the South stratum and generally under 10% in the North stratum) (Figure B.41). Overall, 957 of the 1670 valid survey tows (57%) contained SGR, with the North stratum having a 71% average proportion non-zero tows while the equivalent South stratum proportion was 46%.

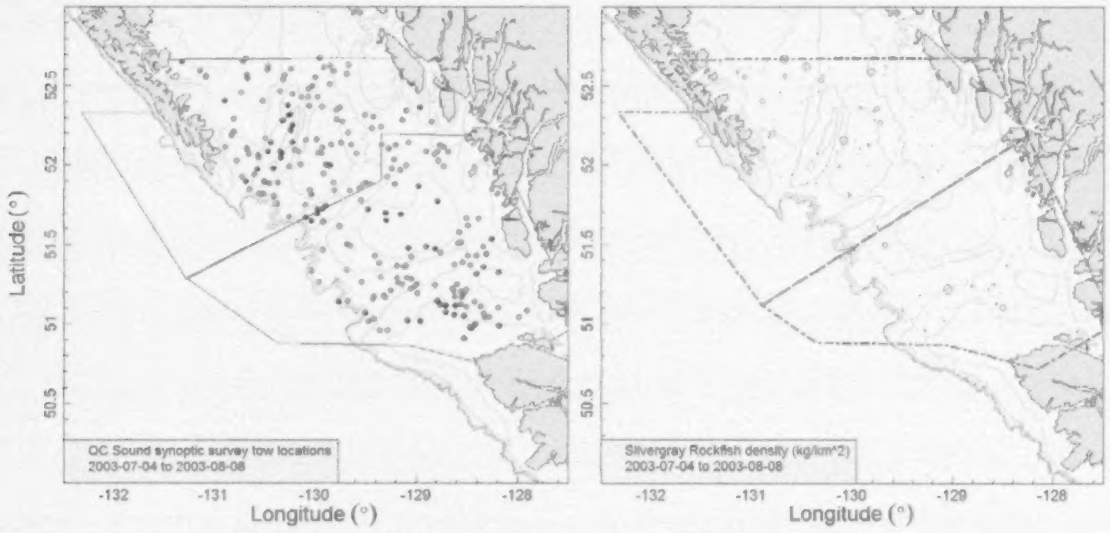

Figure B.32. Valid tow locations (50-125m stratum: black; 126-200m stratum: red; 201-330m stratum: grey; 331-500m stratum: blue) and density plots for the 2003 Queen Charlotte Sound synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2003–2005, 2007, 2009, 2011, 2013), with the largest circle = 57,477 kg/km^2 in 2013. Boundaries delineate the North and South aerial strata.

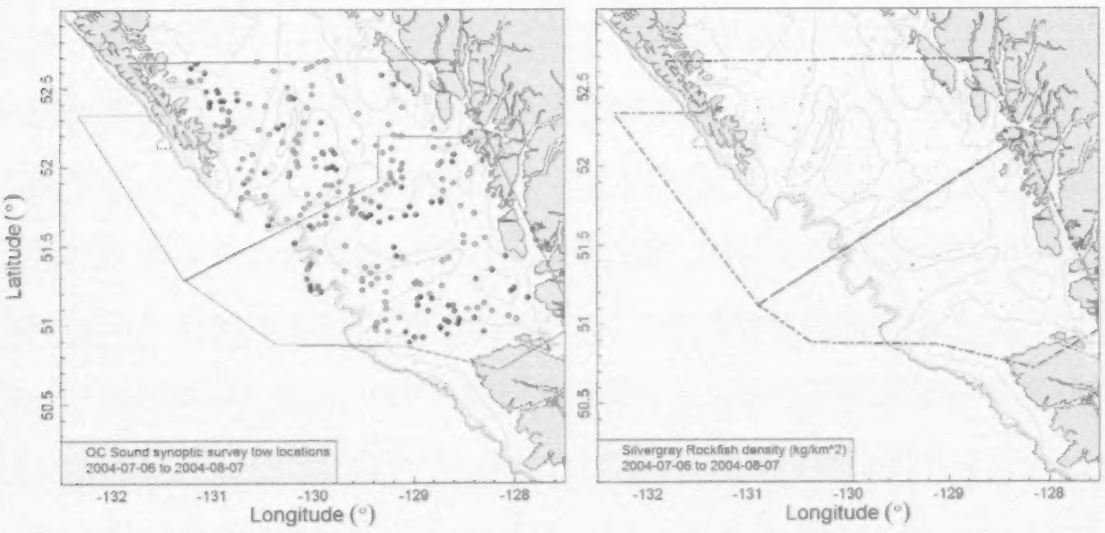

Figure B.33. Tow locations and density plots for the 2004 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

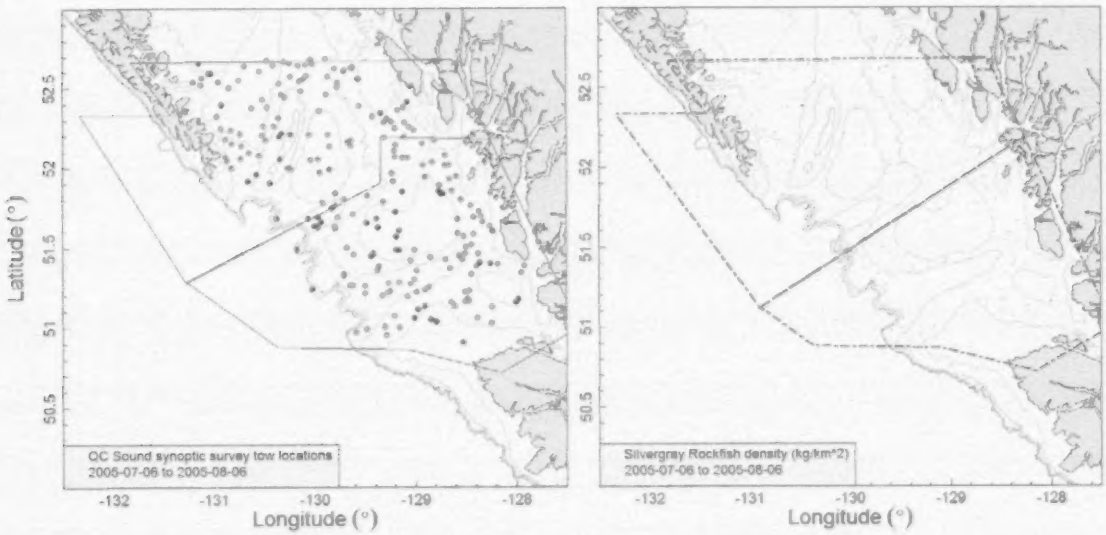

Figure B.34. Tow locations and density plots for the 2005 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

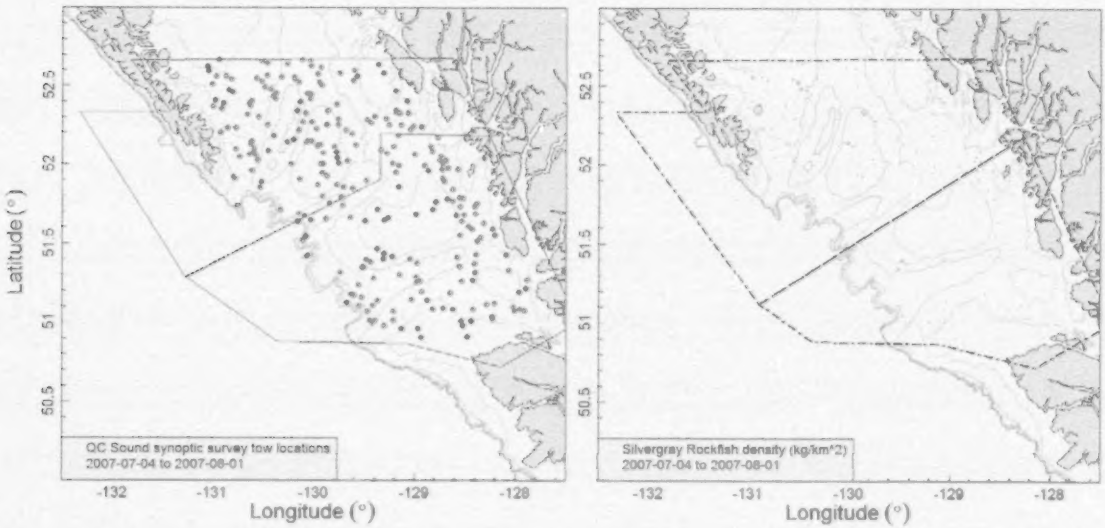

Figure B.35. Tow locations and density plots for the 2007 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

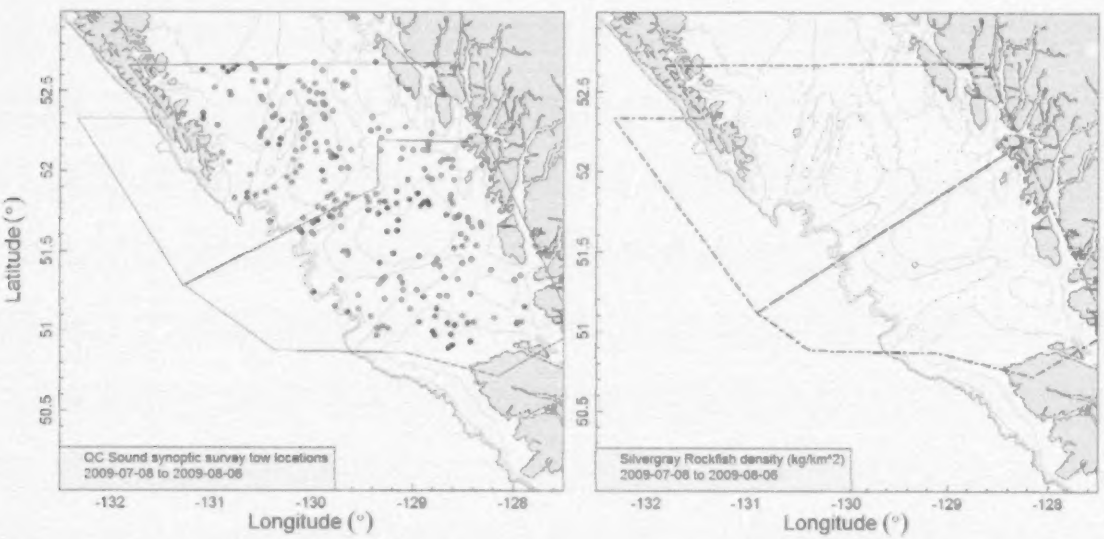

Figure B.36. Tow locations and density plots for the 2009 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

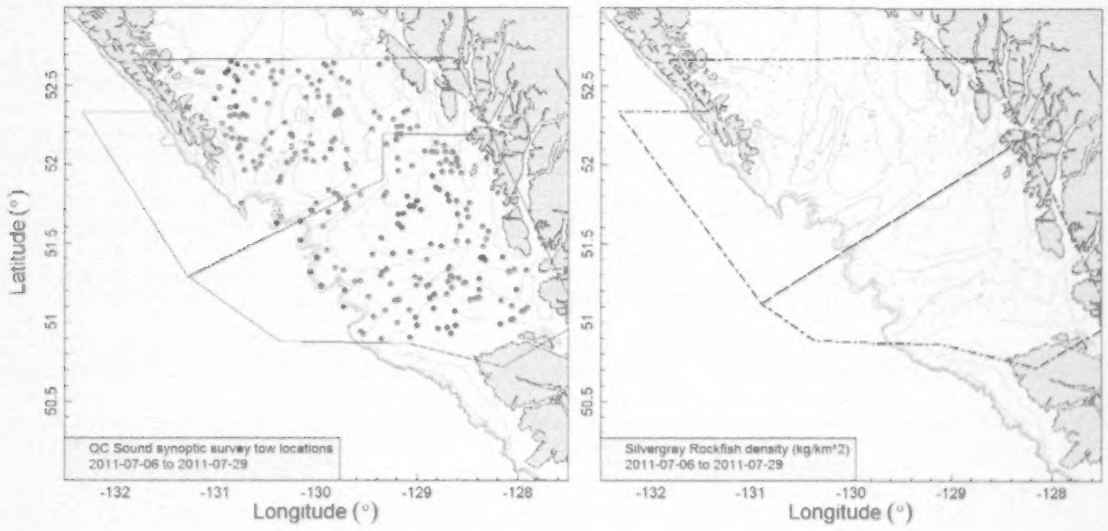

Figure B.37. Tow locations and density plots for the 2011 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

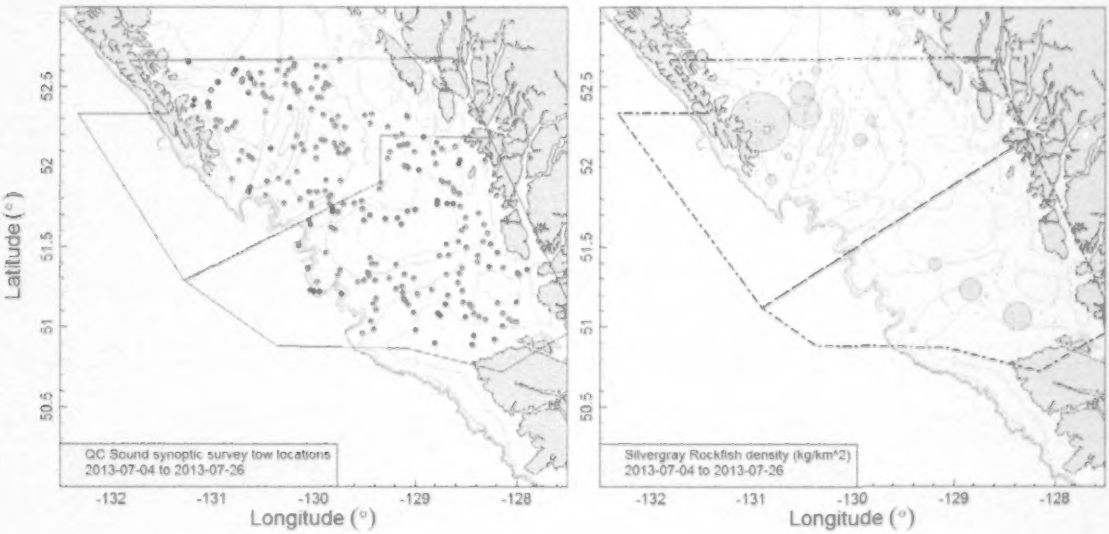

Figure B.38. Tow locations and density plots for the 2013 Queen Charlotte Sound synoptic survey (see Figure B.32 caption).

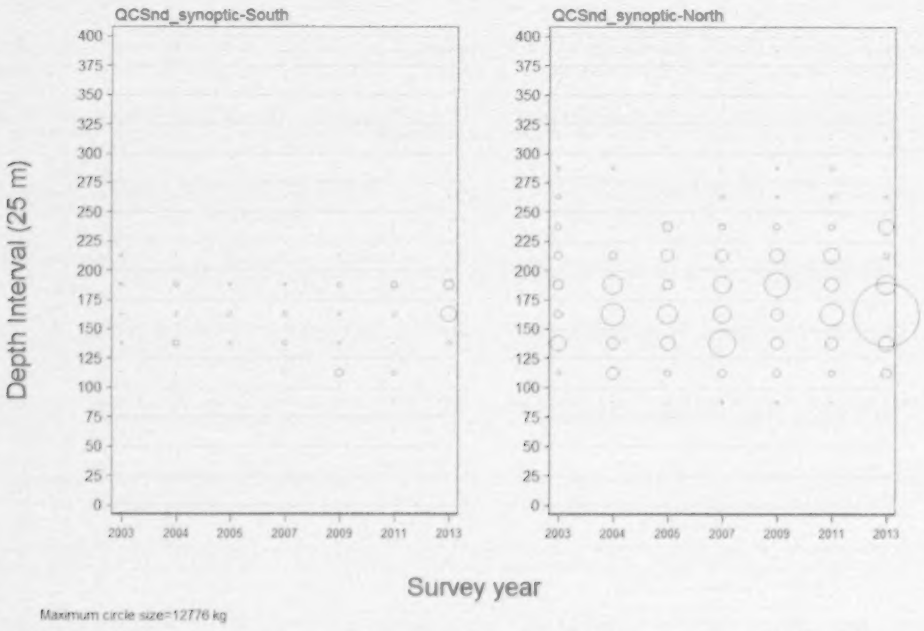

Figure B.39. Distribution of observed catch weights of Silvergray Rockfish for the two main Queen Charlotte Sound synoptic survey aerial strata (Table B.13) by survey year and 25 m depth zone. Depth zones are indicated by the mid point of the depth interval and circles in the panel are scaled to the maximum value (12,776 kg) in the 150-175 m interval in 2013. The 1% and 99% quantiles for the SGR empirical start of tow depth distribution= 78 m and 311 m respectively.

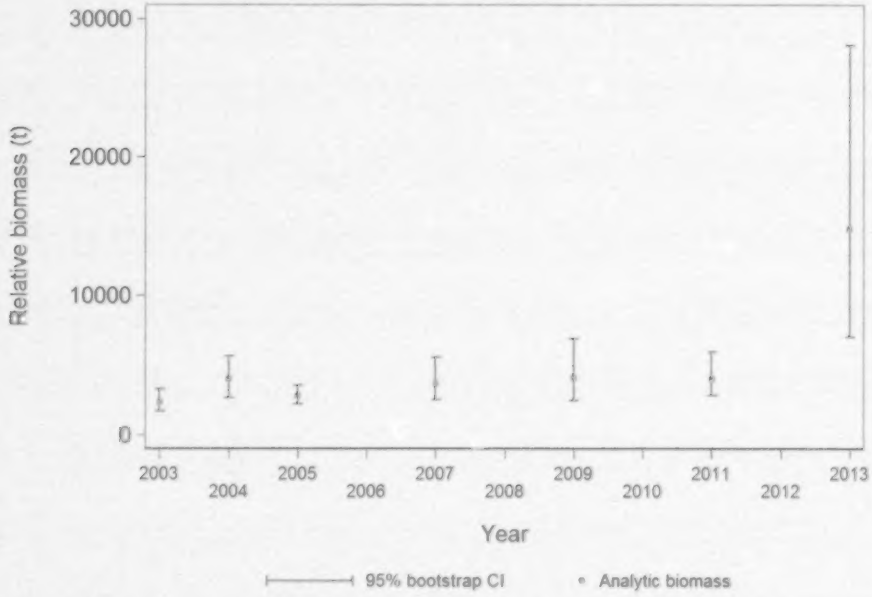

Figure B.40. Plot of biomass estimates for SGR (values provided in Table B.15) from the Queen Charlotte Sound synoptic survey over the period 2003 to 2013. Bias corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

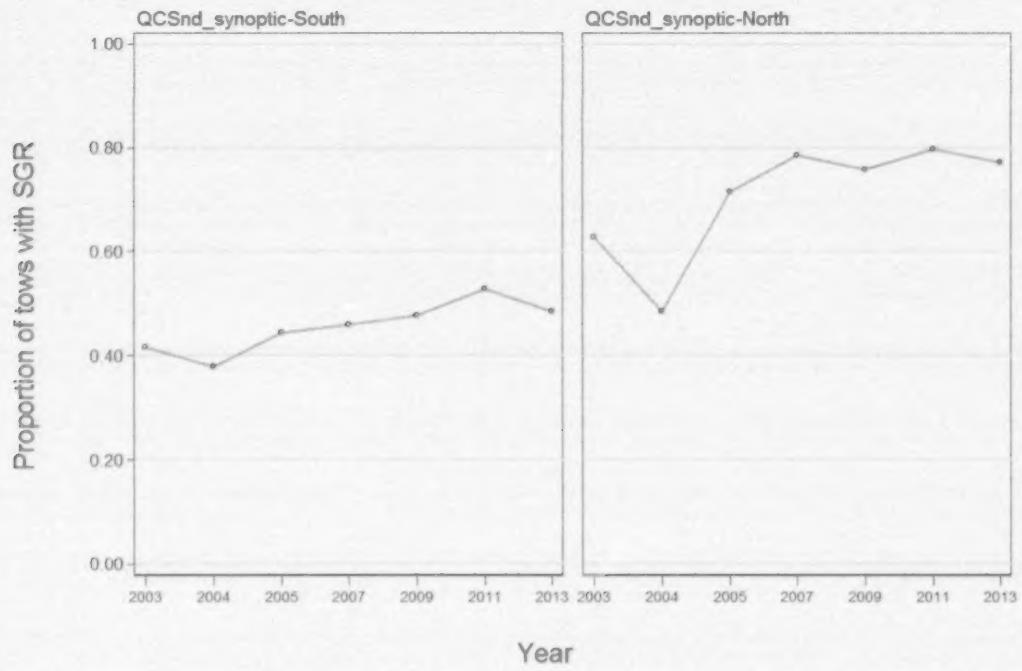

Figure B.41. Proportion of tows by stratum and year which contain SGR from the Queen Charlotte Sound synoptic survey over the period 2003 to 2013.

B.8. WEST COAST VANCOUVER ISLAND SYNOPTIC TRAWL SURVEY

B.8.1. Data selection

This survey has been conducted five times in the period 2004 to 2012 off the west coast of Vancouver Island by the RV W.E. Ricker. It comprises a single aerial stratum, separated into four depth strata: 50-125 m; 125-200 m; 200-330 m; and 330-500 m (Table B.16). Approximately 150 to 180 2-km^2 blocks are selected randomly among the four depth strata when conducting each survey (Olsen et. al. 2009).

Table B.16. Stratum designations, number of usable and unusable tows, for each year of the west coast Vancouver Island synoptic survey. Also shown is the area of each stratum and the start and end dates for each survey.

Survey year	Stratum depth zone				Total Tows[1]	Unusable tows	Start date	End date
	50-125 m	125-200 m	200-330 m	330-500 m				
2004	35	34	13	8	89	16	26-May-04	09-Jun-04
2006	62	63	28	13	164	10	24-May-06	18-Jun-06
2008	54	51	34	24	159	15	27-May-08	21-Jun-08
2010	58	47	22	10	136	7	08-Jun-10	28-Jun-10
2012	61	46	26	20	153	4	23-May-12	15-Jun-12
Area (km^2)	6,180	3,936	752	688	11,556[2]	–	–	–

[1] GFBio usability codes=0,1,2,6

[2] Total area (km^2) for 2012 synoptic survey

A "doorspread density" value was generated for each tow based on the catch of Silvergray Rockfish, the mean doorspread for the tow and the distance travelled (Eq. B.4). The distance travelled was provided as a data field, determined directly from vessel track information collected during the tow. There were only two missing values in this field which were filled in by multiplying the vessel speed by the time that the net was towed. There were a large number of missing values for the doorspread field, which were filled in using the mean doorspread for the survey year or a default value of 64.4 m for the three years with no doorspread data (Table B.17). The default value is based on the mean of the observed doorspread from the net mensuration equipment.

Table B.17. Number of tows with and without doorspread measurements by survey year for the WCVI synoptic survey. Mean doorspread values for those tows with measurements are provided.

	Number tows		Mean
	Without doorspread	With doorspread	doorspread (m)
2004	90	–	–
2006	98	69	64.3
2008	60	107	64.5
2010	137	–	–
2012	153	–	–
All surveys	538	176	64.4

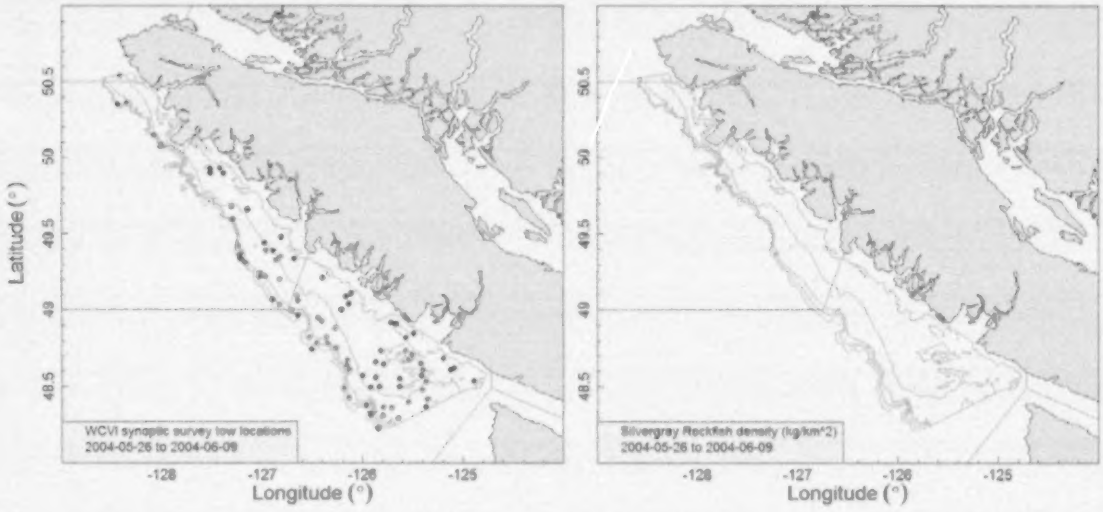

Figure B.42. Valid tow locations (50-125m stratum: black; 126-200m stratum: red; 201-330m stratum: grey; 331-500m stratum: blue) and density plots for the 2004 west coast Vancouver Island synoptic survey. Circle sizes in the right-hand density plot scaled across all years (2004, 2006, 2008, 2010, 2012), with the largest circle = 25,419 kg/km^2 in 2012. The red solid lines indicate the boundaries for PMFC areas 3C and 3D.

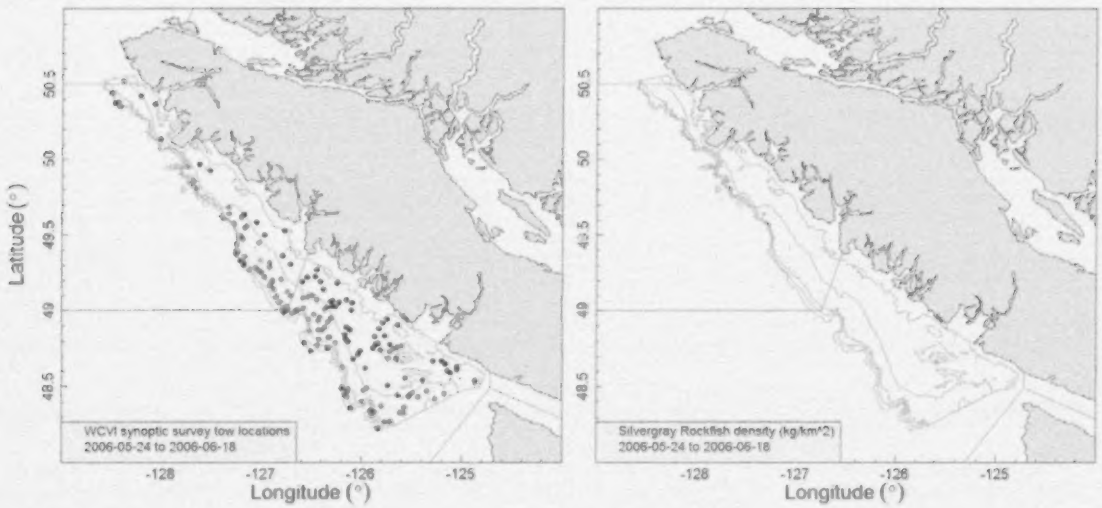

Figure B.43. Tow locations and density plots for the 2006 west coast Vancouver Island synoptic survey (see Figure B.42 caption).

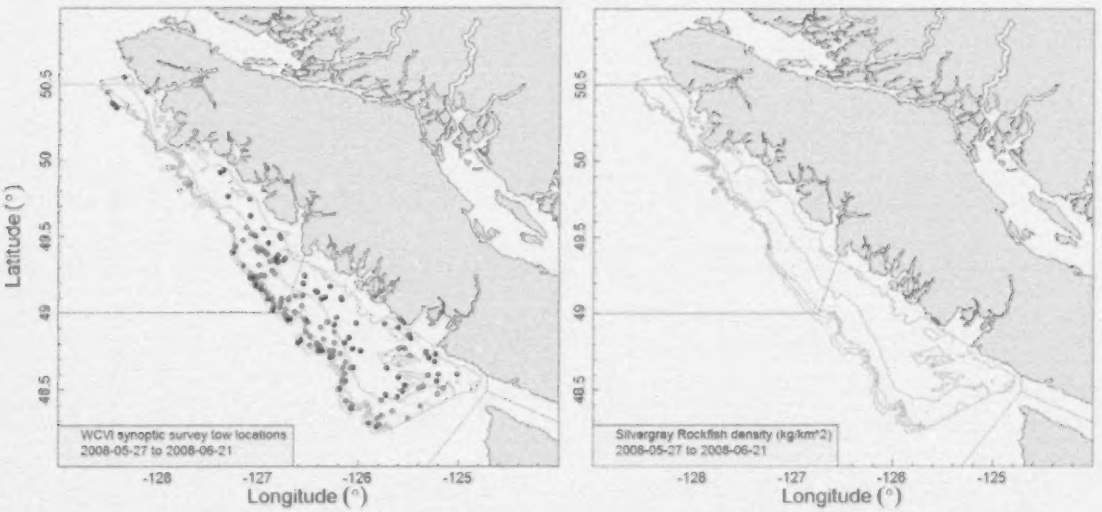

Figure B.44. Tow locations and density plots for the 2008 west coast Vancouver Island synoptic survey (see Figure B.42 caption).

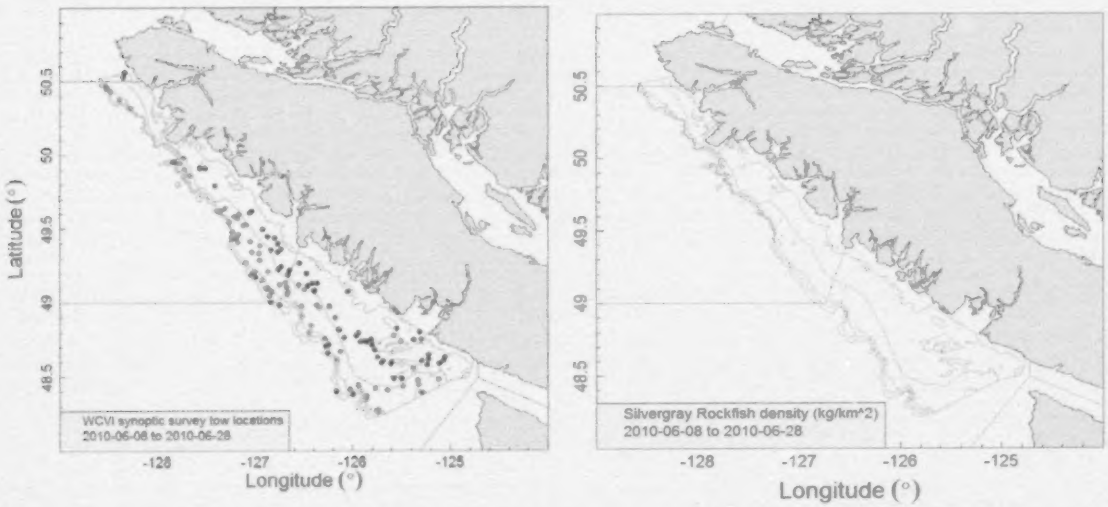

Figure B.45. Tow locations and density plots for the 2010 west coast Vancouver Island synoptic survey (see Figure B.42 caption).

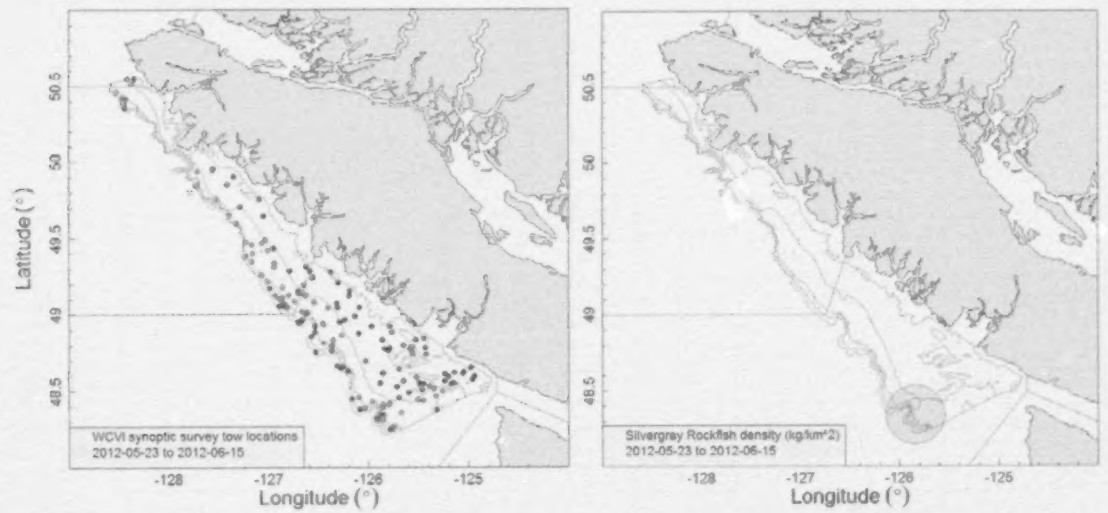

Figure B.46. Tow locations and density plots for the 2012 west coast Vancouver Island synoptic survey (see Figure B.42 caption).

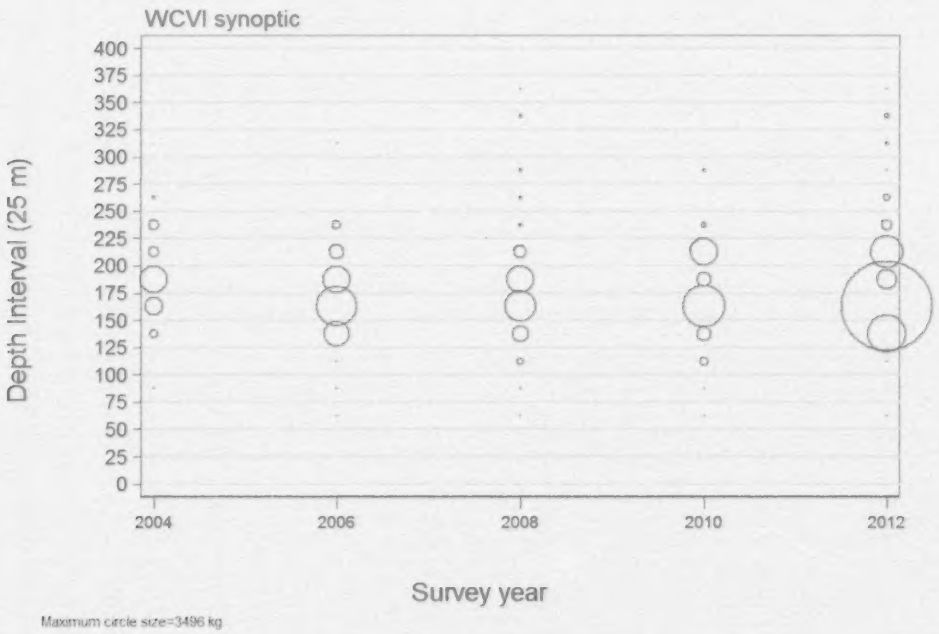

Figure B.47. Distribution of observed weights of Silvergray Rockfish by survey year and 25 m depth zone. Depth zones are indicated by the mid-point of the depth interval. Minimum and maximum depths observed for SGR: 55 m and 430 m, respectively.

B.8.2. Results

Silvergray Rockfish were mainly taken at depths from 100 to 300 m, but there were sporadic observations at depths up to about 360 m (Figure B.47). Estimated biomass levels for Silvergray Rockfish from this trawl survey were low for the first three surveys, but then nearly tripled compared to the average of the first three surveys in 2010 and went up more than 5 times the early average in 2012 (Figure B.48; Table B.18). The estimated CVs ranged between 22% and 44% over the first four surveys (the 2010 survey was 29%), while the CV for the 2012 survey reached 72% (Table B.18). Silvergray Rockfish appear to be an aggregated species which makes it less than ideal to monitor with trawl gear, resulting in CVs which can exceed 40-50%.

The proportion of tows capturing Silvergray Rockfish ranged consistently between 21 and 32% for the five synoptic surveys, with a mean value of 28% (Figure B.49). There was an increasing trend in the proportion of tows with SGR, with the final three survey years at values near or above 30% (Figure B.49).

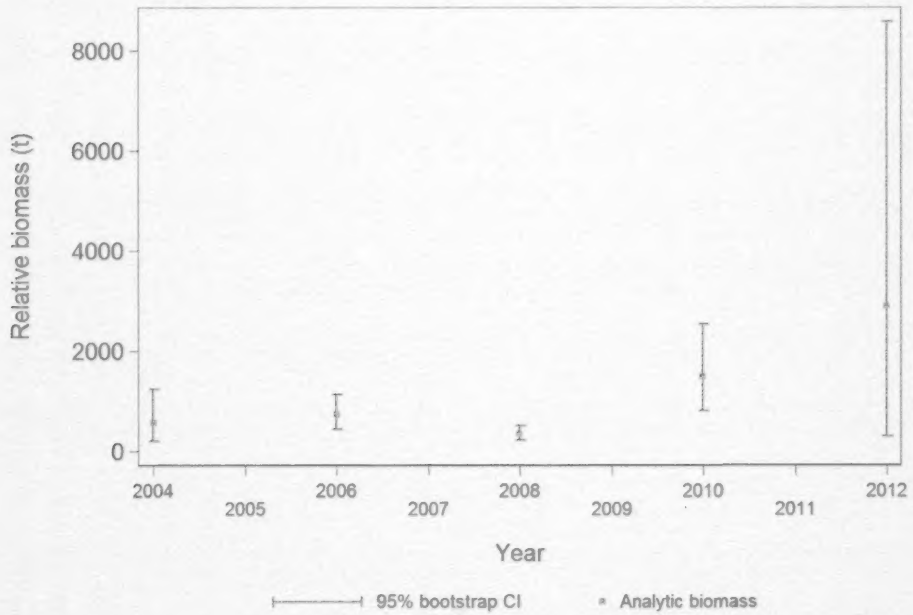

Figure B.48. Plot of biomass estimates for Silvergray Rockfish from the 2004 to 2012 west coast Vancouver Island synoptic trawl surveys (Table B.16). Bias-corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

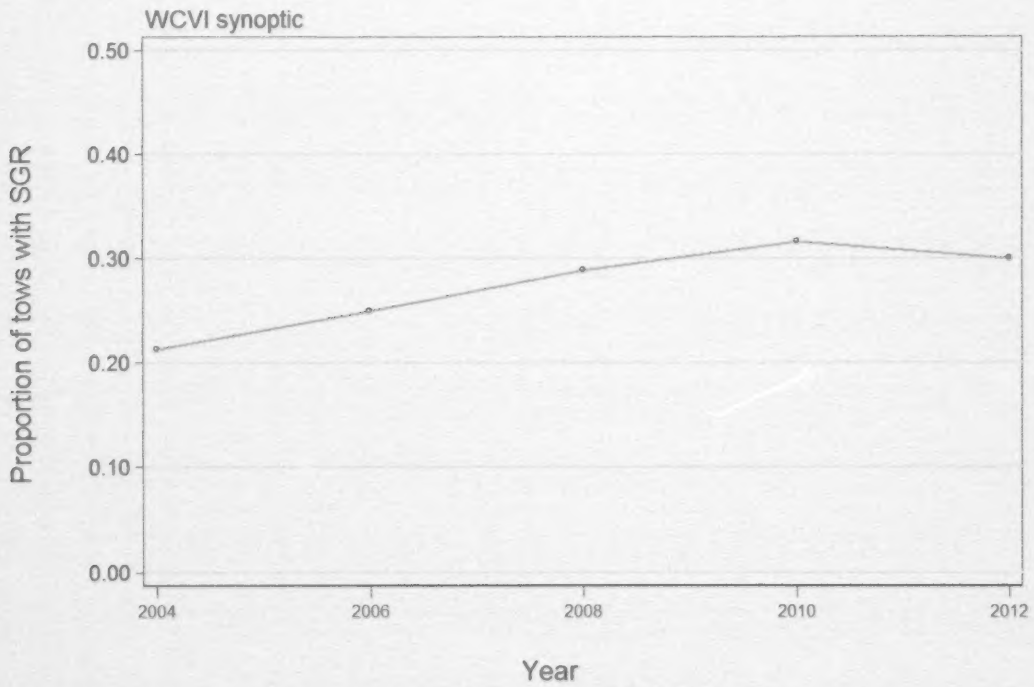

Figure B.49. Proportion of tows by stratum and year capturing Silvergray Rockfish in the WCVI synoptic trawl surveys, 2004–2012.

Table B.18. Biomass estimates for Silvergray Rockfish from the WCVI synoptic trawl survey for the survey years 2004 to 2012. The 1996 Caledonian survey areas by stratum were increased to match the equivalent 2012 WCVI synoptic strata (see Table B.16). Bootstrap bias-corrected confidence intervals and CVs are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
2004	571	571	201	1,228	0.444	0.439
2006	721	721	426	1,122	0.251	0.249
2008	336	337	214	511	0.220	0.220
2010	801	806	427	1,359	0.290	0.297
2012	2,893	3,017	281	8,588	0.719	0.752

The five WCVI synoptic survey indices spanning the period 2004 to 2012 were accepted as a linked series of abundance indices for use in the stock assessment model (described in Appendix D). The 1996 survey index from the vessel Caledonian was not accepted into this series because of the substantial difference in timing for this survey (September) compared to the timing of the synoptic surveys (late spring). It was felt that this difference would lead to varying availability for this species between surveys and consequently there would be a difference in comparability between this survey and remaining five synoptic surveys.

B.9. WEST COAST HAIDA GWAII SYNOPTIC TRAWL SURVEY AND THE 1997 WEST COAST HAIDA GWAII OCEAN SELECTOR SURVEY

B.9.1. Data selection

The west coast Haida Gwaii (WCHG) survey has been conducted five times in the period 2006 to 2012 off the west coast of Haida Gwaii. It comprises a single aerial stratum extending from 53°N to the BC-Alaska border and east to 133°W (e.g., Olsen et al. 2008). The 2006 survey used a different depth stratification scheme compared to the later synoptic surveys: 150–200 m, 200–330 m, 330–500 m, 500–800 m, and 800–1300 m (Workman et al. 2007). All tows from this survey were re-stratified into the four depth strata used from 2007 onwards: 180–330 m; 330–500 m; 500–800 m; and 800–1300 m, based on the mean of the beginning and end depths of each tow (Table B.19). Plots of the locations of all valid tows by year and stratum are presented in Figure B.51 (2006), Figure B.52 (2007), Figure B.53 (2008), Figure B.54 (2010) and Figure B.55 (2012). Note that the depth stratum boundaries for this survey differ from those used for the Queen Charlotte Sound (Edwards et al., 2012a) and west coast Vancouver Island (Edwards et al., 2014b) synoptic surveys due to the considerable difference in the seabed topography of the area being surveyed. The deepest stratum (800–1300 m) was omitted from this analysis because of lack coverage in 2007.

A survey using the *Ocean Selector* was conducted in September 1997 (Workman et al. 1998), using a design that closely resembled that subsequently used for the WCHG synoptic survey, including the random selection of survey blocks and the use of Atlantic Western II box trawl net (Figure B.50, Table B.19). Tow times were set at 15 minutes, which was similar to the 20 minute target tow period used in the synoptic survey. Given the similarity in design, the familiarity of the skipper with this section of the coast and the use of three different vessels in the synoptic surveys (Table B.19), it seemed reasonable to link this survey with the four WCHG synoptic surveys conducted from 2006. Two tows conducted by this survey off the southern end of Moresby Island were dropped because the WCHG synoptic survey did not go south of 53°N latitude in 2007 and 2010, and none of the five synoptic surveys went as far south as the 1997 survey. The 1997 survey used a different depth stratification scheme compared to the later synoptic surveys: 180–275 m, 275–365 m, 365–460 m, 460–625 m, with the depth of all tows

ranging from 166 m to 573 m (based on the mean of beginning and end depths). These tows were re-stratified to the WCHG stratum scheme used from 2007 onwards, taking the depth of the tow as the mean of the beginning and end depths of the tow (Table B.19).

A "doorspread density" value (Eq. B.4) was generated for each tow based on the catch of Silvergray Rockfish, the mean doorspread for the tow and the distance travelled for both the WCHG and the 1997 Selector survey. The distance travelled was determined directly by measuring the tow path for all six surveys. There were no missing values in the distance travelled field for these six surveys, but there were some missing doorspread values in valid tows from the five synoptic surveys, which had mean doorspread values that ranged from 69 m to 81 m (Table B.20). Missing doorspread values were replaced with the mean doorspread for the survey year. The 1997 Ocean Selector survey had no associated doorspread values for any of its tows because net mensuration instruments were not present at the time of the survey.

There were inconsistencies in the reported net dimensions for the 1997 survey in Workman et al. (1998), with Figure 3 of that document reporting 46 m as the combined length of the bridle plus sweeps, while the same dimension was reported as 55 m in the text of the document. Interviews with skippers who were active at the time, including Dave Clattenberg, the skipper of the 1997 Selector survey, indicated that the 55 m dimension was correct. Fifty-five metres was also the length of the bridle and sweeps used for the synoptic surveys. Consequently, the mean doorspread observed over all four synoptic surveys (76.6 m) (Table B.20) was used to populate the missing doorspread field for the 1997 Ocean Selector survey. Stratum areas were held constant for all five surveys (Table B.19).

Table B.19. Stratum designations, vessel name, number of usable and unusable tows, for each year of the west coast Haida Gwaii synoptic survey as well as the 1997 Ocean Selector survey. Also shown are the area of each stratum and the dates of the first and last survey tow in each year.

		Depth stratum							
Survey year	Vessel	180-330m	330-500m	500-800m	800-1300m	Total tows[1]	Unusable tows	Minimum date	Maximum date
1997	Ocean Selector	39[2]	57	6	–	102[2]	5	07-Sep-97	21-Sep-97
2006	Viking Storm	54	27	18	11	110	13	30-Aug-06	22-Sep-06
2007	Nemesis	68	34	9	–	111	5	14-Sep-07	12-Oct-07
2008	Frosti	71	31	8	8	118	9	28-Aug-08	18-Sep-08
2010	Viking Storm	82	29	12	5	128	3	28-Aug-10	16-Sep-10
2012	Nordic Pearl	75	29	10	15	129	12	27-Aug-12	16-Sep-12
Area (km^2)		1104	1028	956	2248	5336[3]	–	–	–

[1] GFBio usability codes=0,1,2,6; [2] excludes 2 tows S of 53°N; [3] Total area (km^2)

Table B.20. Number of valid tows with doorspread measurements, the mean doorspread values (in m) from these tows for each survey year and the number of valid tows without doorspread measurements.

Year	Tows with doorspread	Tows missing doorspread	Mean doorspread (m)
2006	93	30	77.7
2007	113	3	68.5
2008	123	4	80.7
2010	129	2	79.1
2012	92	49	73.8
Total/Average	550	88	76.6[1]

[1] average 2006–2010: all observations

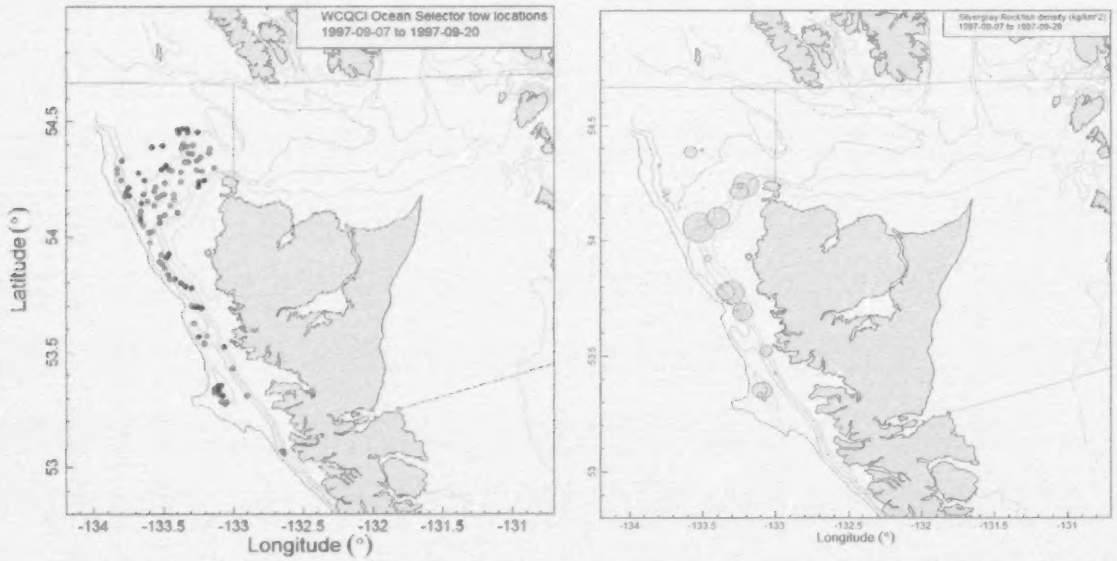

Figure B.50. Valid tow locations (180-330m stratum: black; 330-500m stratum: red; 500-800m stratum: grey) and density plots for the 1997 Ocean Selector random survey. Circle sizes in the right-hand density plot scaled across all years (1997, 2006–2010), with the largest circle = 19,257 kg/km^2 in 2006. The red lines show the Pacific Marine Fisheries Commission 5E and 5D major area boundaries.

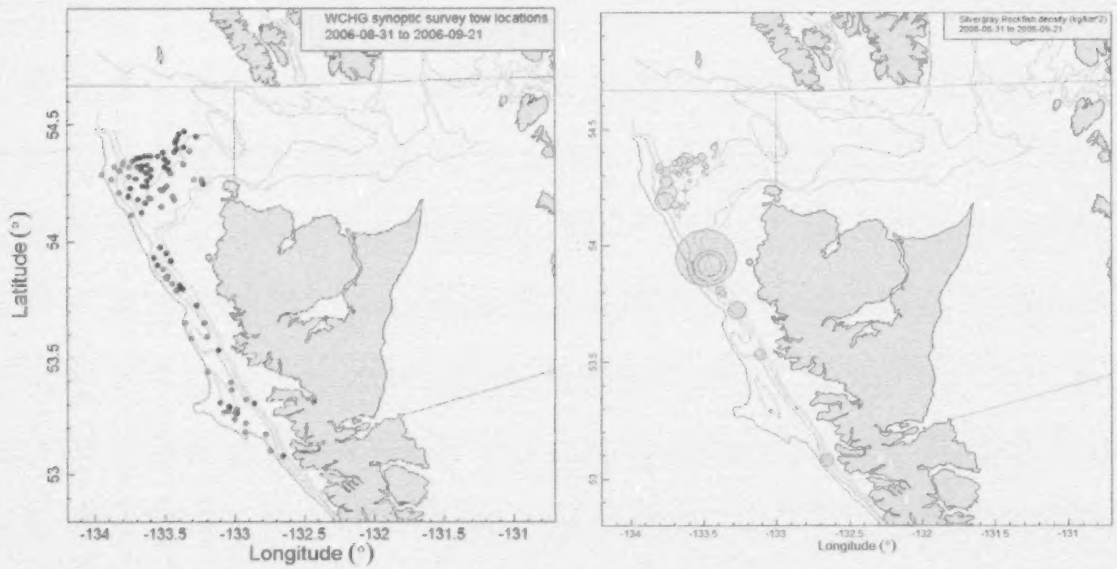

Figure B.51. Tow locations and density plots for the 2006 Viking Storm synoptic survey (see Figure B.50 caption).

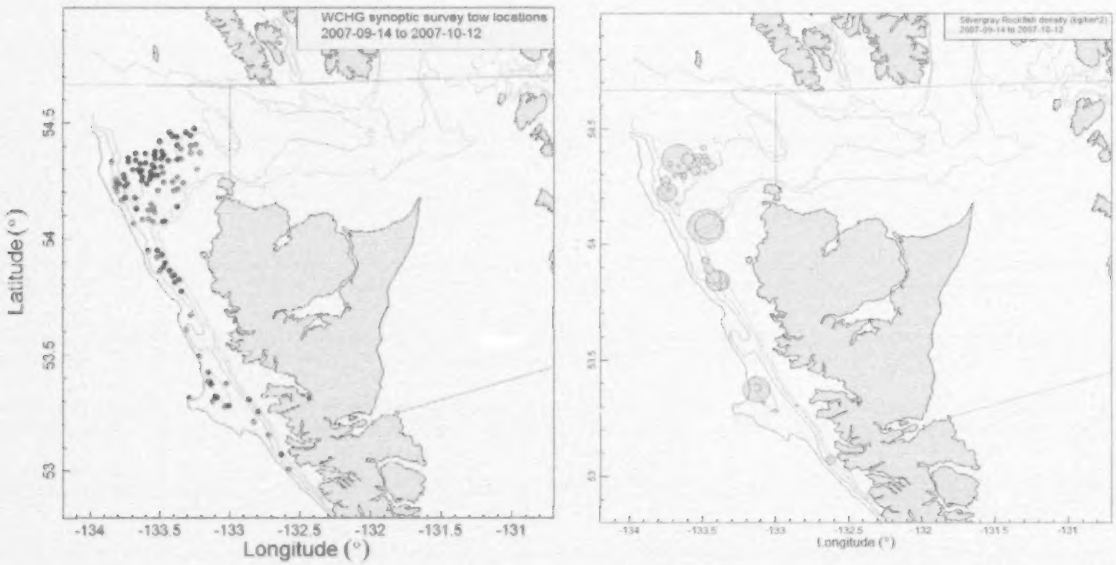

Figure B.52. Tow locations and density plots for the 2007 Nemesis synoptic survey (see Figure B.50 caption).

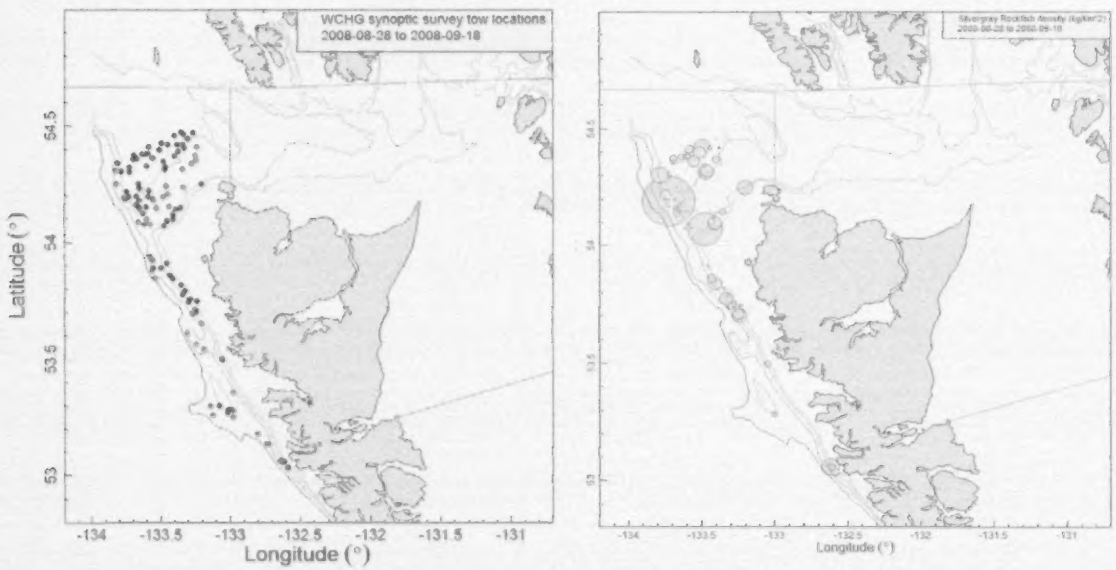

Figure B.53. Tow locations and density plots for the 2008 Frosti synoptic survey (see Figure B.50 caption).

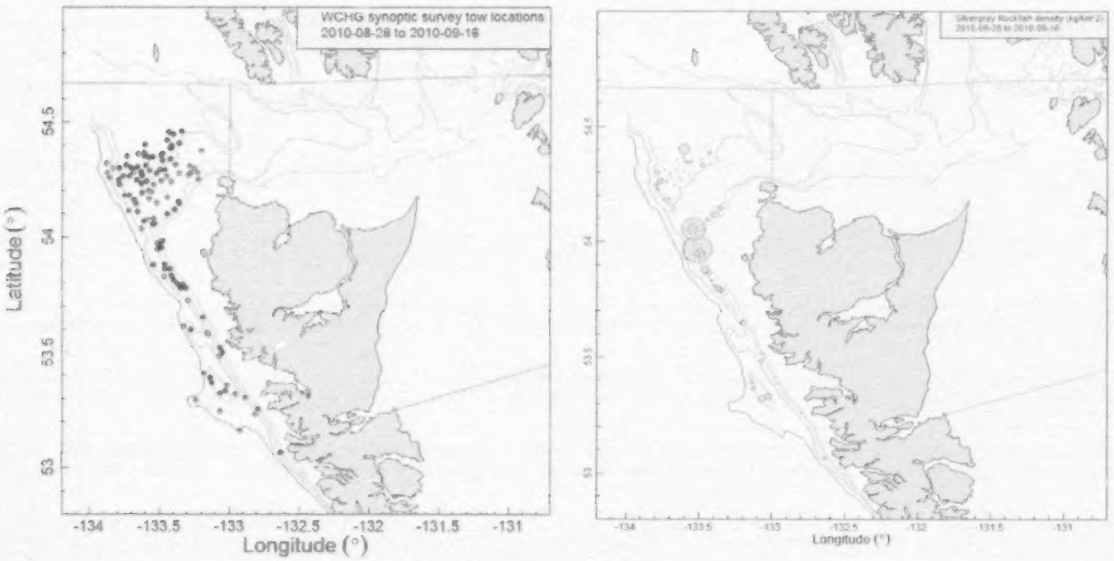

Figure B.54. Tow locations and density plots for the 2010 Viking Storm synoptic survey (see Figure B.50 caption).

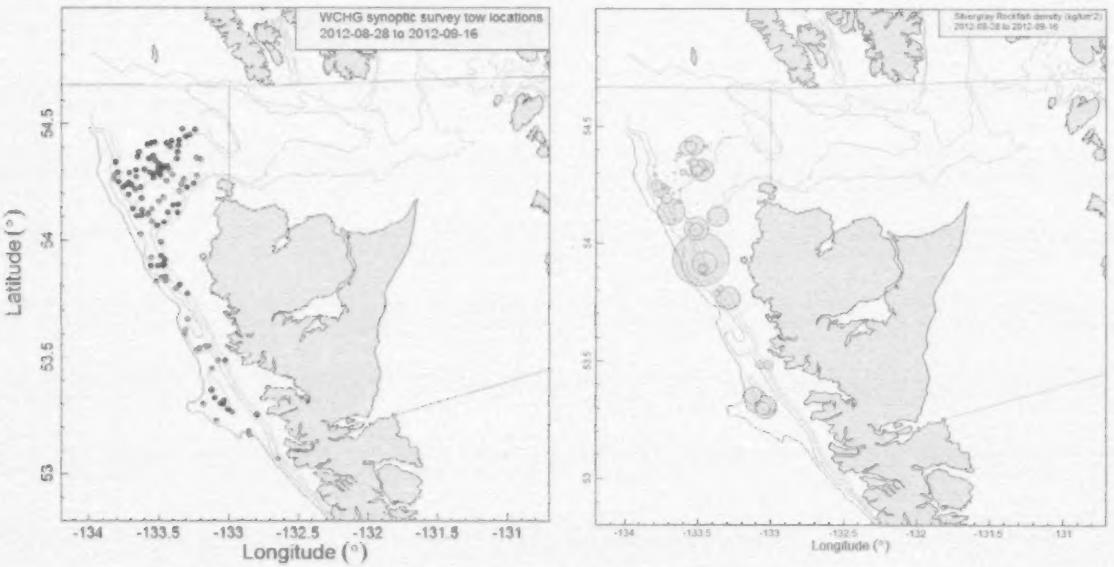

Figure B.55. Tow locations and density plots for the 2012 Viking Storm synoptic survey (see Figure B.50 caption).

B.9.2. Results

Catch densities of Silvergray Rockfish from this survey series were highest off the northwest corner of Graham Island, along with frequent tows containing SGR on a long shallow ridge west of Rennell Sound [Figure B.50 (1997), Figure B.51 (2006), Figure B.52 (2007), Figure B.53 (2008), and Figure B.54 (2010)]. Silvergray Rockfish were mainly taken at depths from 200 to 350 m, with very few observations in the deeper strata (Figure B.56).

Table B.21. Biomass estimates for Silvergray Rockfish from the four west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey. Bootstrap bias-corrected confidence intervals and coefficients of variation (CVs) are based on 1000 random draws with replacement.

Survey Year	Biomass (t)	Mean bootstrap biomass (t)	Lower bound biomass (t)	Upper bound biomass (t)	Bootstrap CV	Analytic CV (Eq. B.6)
1997	1,775	1,791	1,048	2,841	0.246	0.258
2006	1,017	1,000	424	2,105	0.409	0.427
2007	1,217	1,209	734	1,930	0.242	0.248
2008	1,070	1,058	643	1,858	0.277	0.277
2010	566	572	320	958	0.284	0.282
2012	1,358	1,353	866	2,160	0.232	0.231

Estimated biomass levels for Silvergray Rockfish from these trawl surveys were variable with little trend, including the 1997 Ocean Selector survey (Figure B.57; Table B.21). The 1997 Ocean Selector survey was about 50% greater than the mean of six observations while the 2010 survey biomass estimate was 50% below the mean. The estimated CVs for these surveys were moderate, ranging from 23 to 28%, except for 2006, when the CV was 43% (Table B.21). The proportion of tows that captured Silvergray Rockfish in the synoptic surveys ranged from 47 to 67% of the valid tows over the five synoptic survey years, while being less than 40% for the 1997 Ocean Selector survey (Figure B.58).

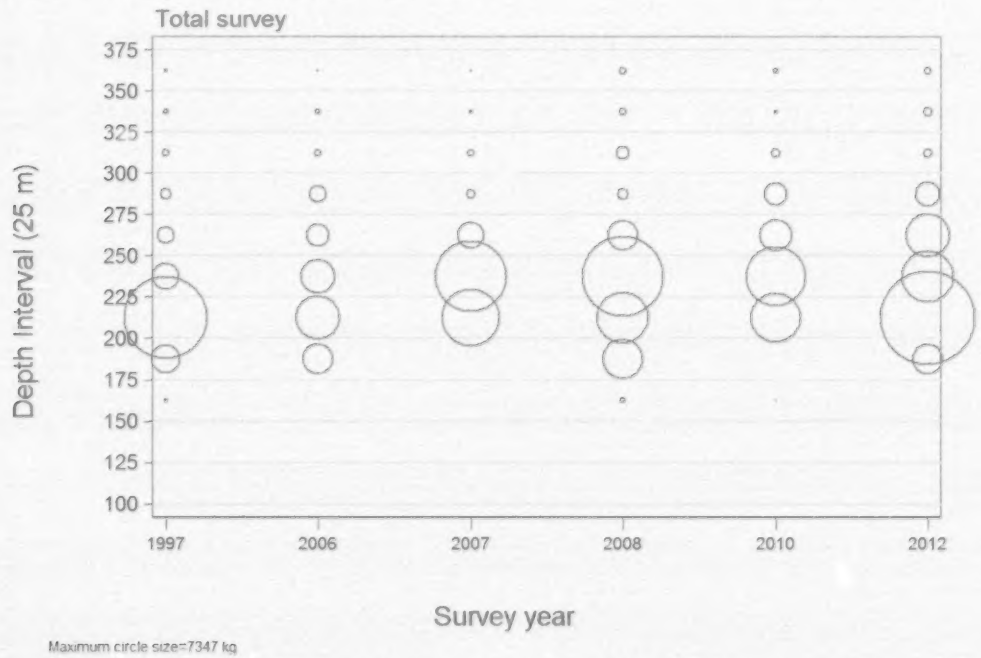

Figure B.56. Distribution of observed weights of Silvergray Rockfish by survey year and 25 m depth zone intervals. Depth zones are indicated by the mid point of the depth interval and circles in the each panel are scaled to the maximum value (7,347 kg – 200-225 m interval in 2012). Minimum and maximum depths observed for SGR: 193 m and 397 m, respectively. Depth is taken at the start position for each tow.

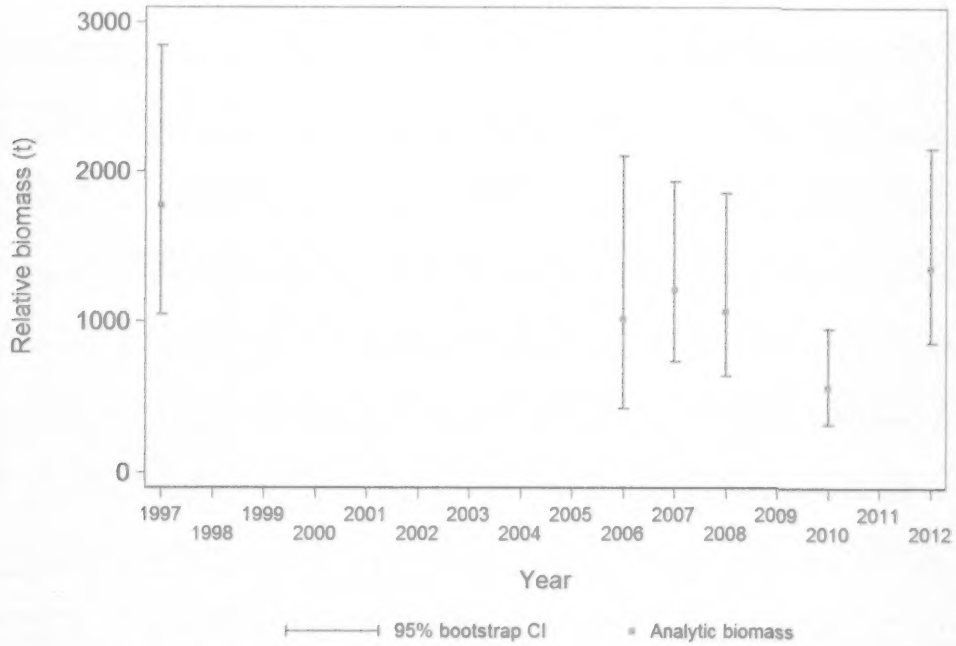

Figure B.57. Biomass estimates for Silvergray Rockfish from the five west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey (Table B.21). Bias-corrected 95% confidence intervals from 1000 bootstrap replicates are plotted.

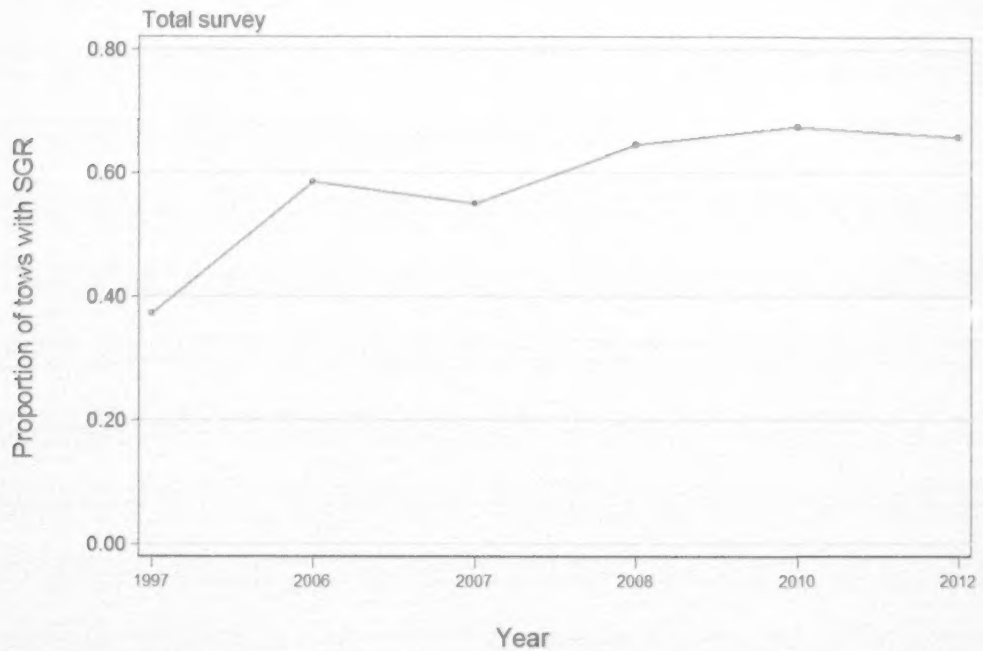

Figure B.58. Proportion of tows by year that contain Silvergray Rockfish for the five west coast Haida Gwaii synoptic surveys and the 1997 Ocean Selector random survey.

APPENDIX C. BIOLOGY

C.1 GROWTH AND MATURITY

C.1.1 Length-Weight

The parameterisation of the length-weight model used in the stock assessment is:

$$W_{si} = \alpha_s (L_{si})^{\beta_s} \tag{C.1}$$

where W_{si} = observed weight (kg) of individual i with sex s,
L_{si} = observed length (cm) of individual i with sex s,
α_s = growth rate scalar for sex s,
β_s = growth rate exponent for sex s.

The above model was fit as a linear regression to the logged length and weight pairs without regard to year or data origin. The resulting estimates for $\log(\alpha_s)$ were exponentiated to provide the α_s parameters used in the stock assessments.

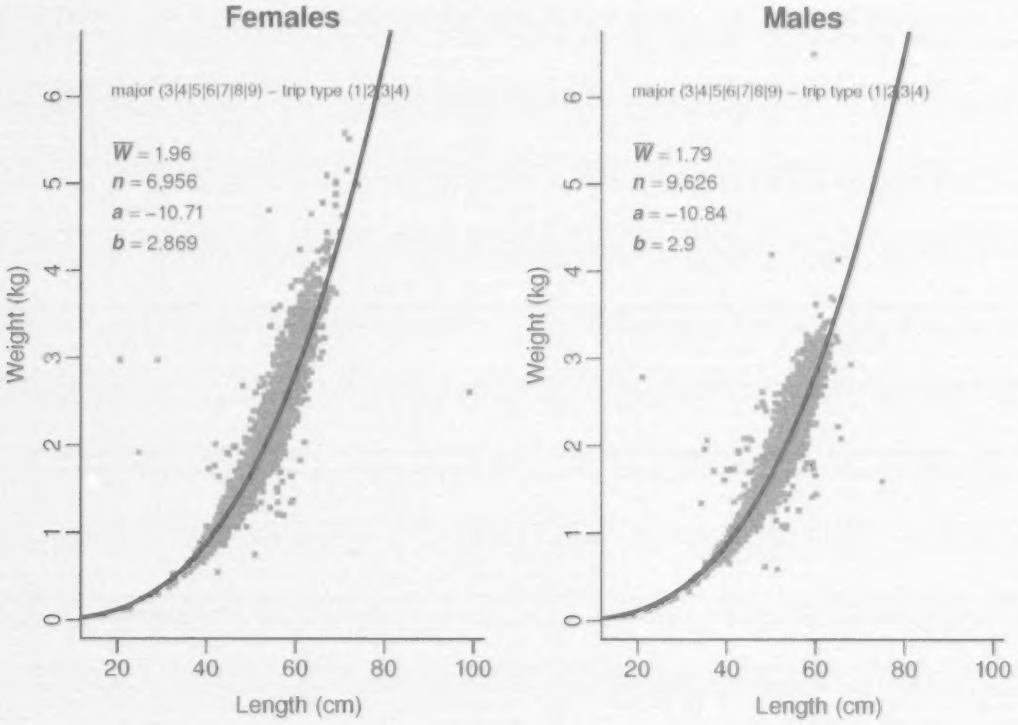

Figure C.1. Regression analyses showing the fitted model and length-weight pairs, without regard to year or data origin, used to estimate α_s and β_s.

Table C.1. Length-weight relationships for specimens collected by commercial and research/survey trips. Specimen sex s: F = female, M = male; n_s = number of specimens by sex; α_s = log(α_s).

s	n_s	α_s	SE$_\alpha$	β_s	SE$_\beta$
Females	6,956	-10.712	0.046171	2.8692	0.011682
Males	9,626	-10.836	0.040685	2.9001	0.010362

C.1.2 von Bertalanffy Growth

The parameterisation of the von Bertalanffy growth model is:

$$L_{as} = L_{\infty,s}\left(1 - \mathrm{e}^{-k_s(a-t_{0,s})}\right) \tag{C.2}$$

where L_{as} = average length (mm) of an individual with sex s at age a,
$L_{\infty,s}$ = average length (mm) of an individual with sex s at maximum age,
k_s = growth rate coefficient for sex s,
$t_{0,s}$ = age at which the average length is 0 for sex s.

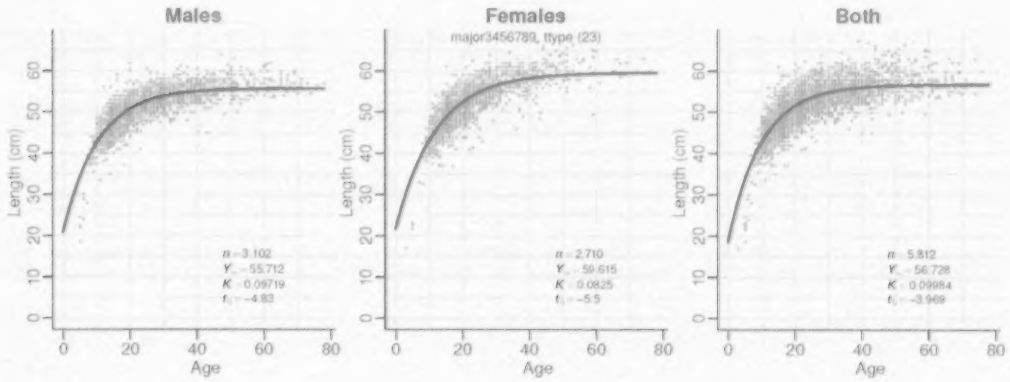

Figure C.2. Length-age relationships using the von Bertalanffy growth model (E2) for Silvergtay Rockfish specimens coastwide collected on research survey trips. n = number of specimens; $Y_\infty = L_{\infty,s}$.

Table C.2. Growth parameters for Silvergray Rockfish using the von Bertalanffy model. Sex s: F= females, M= males; Com= commercial; R/S= research and/or survey.

	s	n_s	$L_{\infty,s}$	k_s	$t_{0,s}$
Com 3CD	M	1,459	57.637	0.075230	-10
	F	1,553	60.427	0.071596	-10
	Both	3,012	59.151	0.072947	-10
Com 5ABC	M	6,892	56.151	0.077728	-10
	F	5,958	60.852	0.065119	-10
	Both	12,850	57.962	0.072637	-10
Com 5DE	M	2,540	57.820	0.069665	-10
	F	2,372	64.208	0.056552	-10
	Both	4,912	60.376	0.063928	-10

Continued on next page

Table C.2. Growth parameters for Silvergray Rockfish using the von Bertalanffy model. Sex s: F= females, M= males; Com= commercial; R/S= research and/or survey.

	s	n_s	$L_{\infty,s}$	k_s	$t_{0,s}$
Com Coast	M	10,891	56.560	0.076159	-10
	F	9,883	61.352	0.064333	-10
	Both	20,774	58.492	0.071194	-10
R/S 3CD	M	691	56.423	0.091722	-5.8435
	F	744	59.909	0.091847	-3.8648
	Both	1,435	57.309	0.10461	-3.2790
R/S 5ABC	M	1,750	55.169	0.10865	-3.1432
	F	1,381	58.995	0.086600	-4.7006
	Both	3,131	56.274	0.10544	-3.0930
R/S 5DE	M	661	56.714	0.077596	-8.2850
	F	585	61.882	0.061432	-10
	Both	1,246	58.022	0.076969	-7.8932
R/S Coast	M	3,102	55.712	0.097191	-4.8298
	F	2,710	59.615	0.082504	-5.4999
	Both	5,812	56.728	0.099835	-3.9690

Non-linear von Bertalanffy models were fit to age-length pairs, with data available up to July 24, 2011, for commercial and research samples from various areas (Table C.2). Only fits from research/survey samples along the BC coast were used in the model (Figure C.2). Generally, females attain larger sizes than do males. Both sexes have sparse data for ages $<$10 y and so the model fits the early growth poorly: t_0 = [-5.5,-4.8] for females and males, respectively. For all fits to the commerical data, the absence of sampled young ages resulted in t_0 hitting an arbitrary constraint at -10 y.

C.1.3 Maturity

A frequency chart of all available maturity data (1967-2013, from the SPECIMEN table in the GFBioSQL database) for Silvergray Rockfish (Figure C.3) suggests that females mature from Oct to January, reach maturity from January to April, become fertilized in May, and release larvae in June-July. Ideally, lengths- and ages-at-maturity are calculated at times of peak development stages (males – inseminations season, females – parturition season; Westrheim 1975). On the other hand, to see changes in maturity it is sometimes best to use data from time periods that ensure a clear delineation between immature and mature fish. Figure C.3 suggests Jul–Sep for females and anytime before June for males. However, data limitations on young ages persuaded us to use the months Apr-Jul for females and Jun-Jul for males.

Using stage 3 and up to denote mature fish, we construct a maturity ogive (Figure C.4) using a double-normal model:

$$m_{as} = \begin{cases} e^{-(a-\nu_s)^2/\rho_{sL}}, & a \leq \nu_s \\ 1, & a > \nu_s \end{cases} \tag{C.3}$$

where m_{as} = maturity at age a for sex s, ν_s = age of full maturity for sex s,
ρ_s = variance for the left limb of the maturity curve for sex s.

This model was fit to proportions-mature using all staged maturity observations with an associated age observation in the months from April to July, regardless of sample origin (either commercial observer or research survey).

Stanley and Kronlund (2000) departed from a previous assessment on Silvergray by using stage 2 and up for mature fish, citing various reasons. We tried this alternative definition of maturity, but (C.3) produced knife-edged curves that we rejected. The proportion of mature individuals is calculated (Table C.3) and the ages of 50% maturity (10.7 y for females and 10.8 y for males) are interpolated from the curves. Stanley and Kronlund (2005) published another maturity ogive that appears to closely match (up to age 13) our stage 3+ ogive using Equation C.3 (Table C.3; Figure C.4).

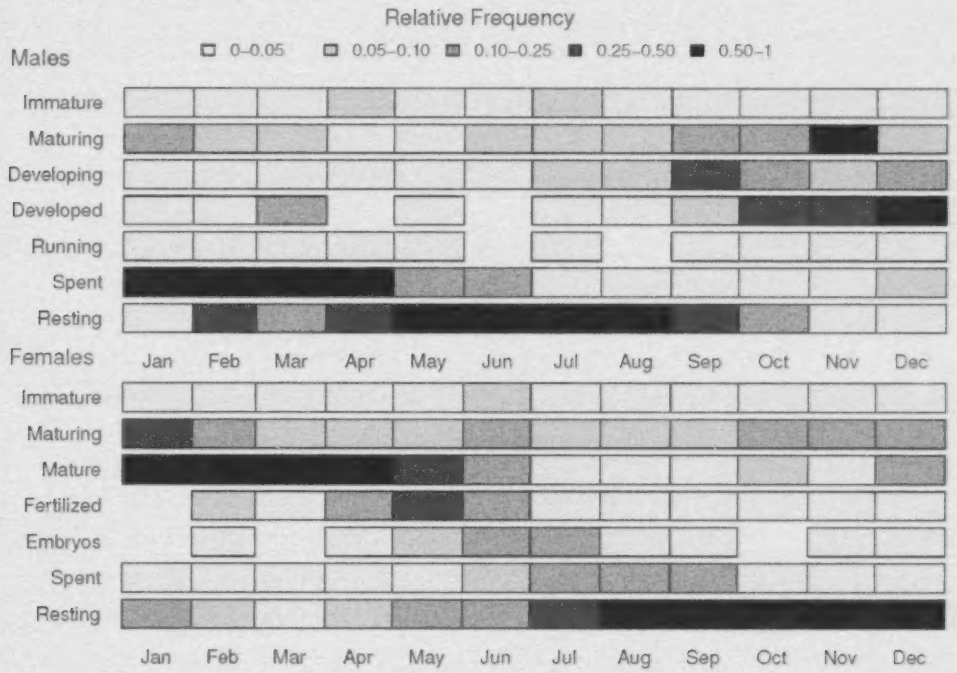

Figure C.3. Relative frequency of maturity codes by month (data stored in DFO's GFBioSQL *database) for Silvergray Rockfish. Frequencies are calculated within each maturity category for every month.*

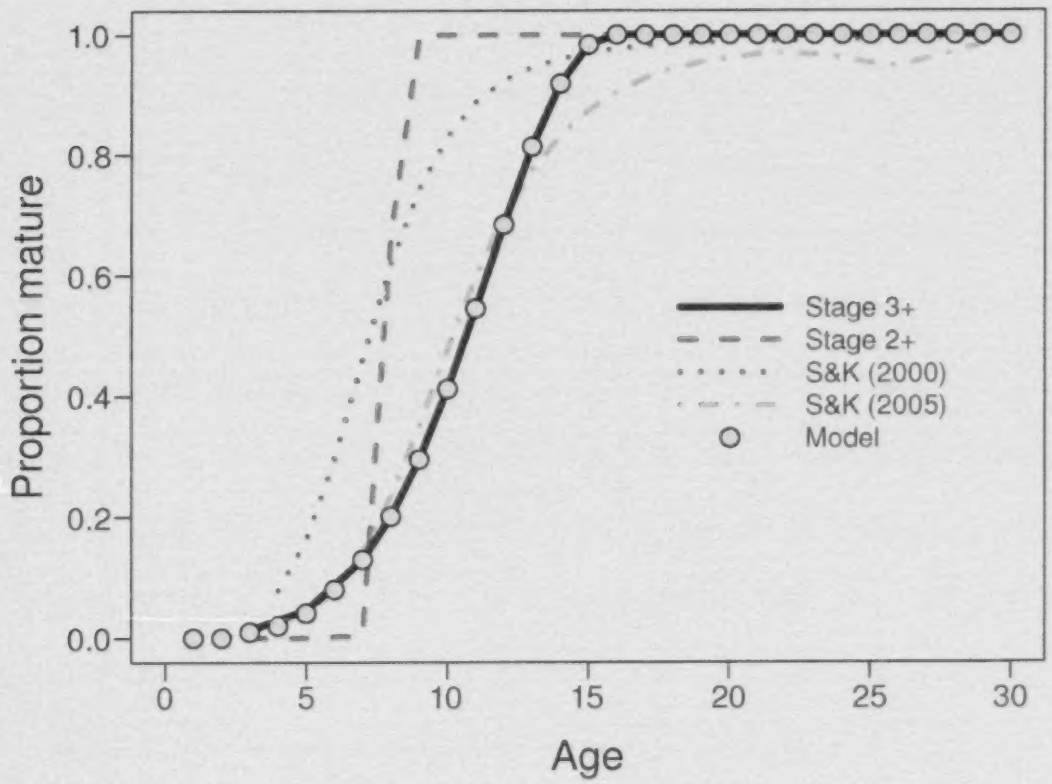

Figure C.4. Maturity ogives for BC Silvergray Rockfish females (data stored in DFO's GFBioSQL database). Solid blue line shows the double-normal fit to data where maturity is defined by stages ≥3; red dashed line indicates fit to stage 2+ maturity; dotted green line indicates fit in Stanley and Kronlund (2000); dahed-dotted orange line indicates fit in Stanley and Kronlund (2005); and open circles mark values used in the model. Age at 50% maturity is roughly 10.7 years.

Table C.3. Proportion of Silvergray Rockfish females (April-July) mature at each age. In this assessment, maturity stages 1 and 2 describe immature fish while stages 3 to 7 are considered mature. Model fits are presented for maturity assuming stage 3+ and stage 2+ using (C.3)*, data in Stanley and Kronlund (2000) and Stanley and Kronlund (2005), and the final model used in this stock assessment.*

Age a	# Fish	Obs. m_a	Fitted Stage3+ m_a	Fitted Stage2+ m_a	Stanley & Kronlund (2000)	Stanley & Kronlund (2005)	Model m_a
1	—	—	—	—	—	0	0
2	—	—	—	—	—	0	0
3	2	0	0.01319	5.083	—	0.01000	0.01000
4	—	—	—	—	0.07900	0.02000	0.02000
5	4	0.2500	0.04595	5.025	0.1630	0.04100	0.04100
6	—	—	—	—	0.2960	0.08000	0.08000
7	1	0	0.1295	0.004301	0.4600	0.1430	0.1295
8	3	0	0.2008	0.6703	0.6200	0.2350	0.2008
9	16	0.1875	0.2953	1	0.7440	0.3520	0.2953
10	39	0.6410	0.4119	1	0.8310	0.4790	0.4119
11	83	0.6988	0.5449	1	0.8880	0.5990	0.5449
12	138	0.6232	0.6838	1	0.9240	0.7000	0.6838
13	158	0.7975	0.8138	1	0.9460	0.7760	0.8138
14	172	0.8547	0.9187	1	0.9600	0.8330	0.9187
15	206	0.8932	0.9836	1	0.9700	0.8750	0.9836
16	205	0.8927	1	1	0.9770	0.9060	1
17	171	0.9006	1	1	0.9820	0.9280	1
18	140	0.9571	1	1	0.9850	0.9440	1
19	108	0.9630	1	1	0.9870	0.9550	1
20	91	0.9560	1	1	0.9880	0.9620	1
21	94	0.9894	1	1	0.9890	0.9680	1
22	88	0.9545	1	1	0.9900	0.9710	1
23	53	0.9811	1	1	0.9910	0.9670	1
24	57	0.9649	1	1	0.9920	0.9620	1
25	50	0.9400	1	1	0.9930	0.9530	1
26	34	0.9706	1	1	0.9940	0.9490	1
27	32	0.9688	1	1	0.9950	0.9600	1
28	41	0.9756	1	1	0.9960	0.9720	1
29	31	1	1	1	0.9970	0.9850	1
30	27	1	1	1	0.9980	0.9920	1

C.2 WEIGHTED AGE PROPORTIONS

This section summarizes a method for representing commercial and survey age structures for a given species through weighting observed age frequencies x_a or proportions x'_a by catch||density in defined strata. (Throughout this section, we use the symbol '||' to delimit parallel values for commercial and survey analyses, respectively, as the mechanics of the weighting procedure are similar for both.) For commercial samples, these strata comprise quarterly periods within a year, while for survey samples, the strata are defined by longitude, latitude, and depth. Within each stratum, commercial ages are weighted by the catch weight (kg) of the species in tows that were sampled, and survey ages are weighted by the catch density (kg/km^2) of the species in sampled tows. A second weighting is then applied: quarterly commercial ages are weighted by the commercial catch weight of the species from all tows within each quarter; stratum survey ages are weighted by stratum areas (km^2) in the survey.

Ideally, sampling effort would be proportional to the amount of the species caught, but this is not usually the case. Personnel can control the sampling effort on surveys more than that aboard commercial vessels, but the relative catch among strata over the course of a year or survey cannot be known with certainty until the events have occurred. Therefore, the stratified weighting scheme presented below attempts to adjust for unequal sampling effort among strata.

For simplicity herein, we illustrate the weighting of age frequencies x_a, unless otherwise specified. The weighting occurs at two levels: h (quarters for commercial ages, strata for survey ages) and i (years if commercial, surveys in series if survey). Notation is summarised in Table C.4.

Table C.4. Equations for weighting age frequencies or proportions for a given species.
*(**c**) = commercial, (**s**) = survey*

Symbol	Description
	Indices
a	age class (1 to A, where A is an accumulator age-class)
d	(**c**) trip IDs as sample units
	(**s**) sample IDs as sample units
h	(**c**) quarters (1 to 4), 91.5 days each
	(**s**) strata (area-depth combinations)
i	(**c**) calendar years (1977 to present)
	(**s**) survey IDs in survey series (e.g., QCS Synoptic)
	Data
x_{adhi}	observations-at-age a for sample unit d in quarter||stratum h of year||survey i
x'_{adhi}	proportion-at-age a for sample unit d in quarter||stratum h of year||survey i
C_{dhi}	(**c**) commercial catch (kg) of a given species for sample unit d in quarter h of year i
	(**s**) density (kg/km^2) of a given species for sample unit d in stratum h of survey i
C'_{dhi}	C_{dhi} as a proportion of total catch||density $C_{hi} = \sum_d C_{dhi}$
y_{ahi}	weighted age frequencies at age a in quarter||stratum h of year||survey i
K_{hi}	(**c**) total commercial catch (kg) of species in quarter h of year i
	(**s**) stratum area (km^2) of stratum h in survey i
K'_{hi}	K_{hi} as a proportion of total catch||area $K_i = \sum_h K_{hi}$
p_{ai}	weighted frequencies at age a in year||survey i
p'_{ai}	weighted proportions at age a in year||survey i

For each quarter||stratum h we weight sample unit frequencies x_{ad} by sample unit catch||density

of the assessment species. (For commercial ages, we use trip as the sample unit, though at times one trip may contain multiple samples. In these instances, multiple samples from a single trip will be merged into a single sample unit.) Within any quarter||stratum h and year||survey i there is a set of sample catches||densities C_{dhi} that can be transformed into a set of proportions:

$$C'_{dhi} = \frac{C_{dhi}}{{}_d C_{dhi}} \ . \tag{C.4}$$

The proportion C'_{dhi} is used to weight the age frequencies x_{adhi} summed over d, which yields weighted age frequencies by quarter||stratum for each year||survey:

$$y_{ahi} = \sum_d \left(C'_{dhi} x_{adhi} \right) \ . \tag{C.5}$$

This transformation reduces the frequencies x from the originals, and so we rescale (multiply) y_{ahi} by the factor

$$\frac{{}_a x_{ahi}}{{}_a y_{ahi}} \tag{C.6}$$

to retain the original number of observations. (For proportions x' this is not needed.) Although we perform this step, it is strictly not necessary because at the end of the two-step weighting, we standardise the weighted frequencies to represent proportions-at-age.

At the second level of stratification by year||survey i, we calculate the the annual proportion of quarterly catch (t) for commercial ages or the survey proportion of stratum areas (km^2) for survey ages

$$K'_{hi} = \frac{K_{hi}}{{}_h K_{hi}} \tag{C.7}$$

to weight y_{ahi} and derive weighted age frequencies by year||survey:

$$p_{ai} = \sum_h \left(K'_{hi} y_{ahi} \right) \ . \tag{C.8}$$

Again, if this transformation is applied to frequencies (as opposed to proportions), it reduces them from the original, and so we rescale (multiply) p_{ai} by the factor

$$\frac{{}_a y_{ai}}{{}_a p_{ai}} \ . \tag{C.9}$$

to retain the original number of observations.

Finally, we standardise the weighted frequencies to represent proportions-at-age:

$$p'_{ai} = \frac{p_{ai}}{{}_a p_{ai}} \ . \tag{C.10}$$

If initially we had used proportions x'_{adhi} instead of frequencies x_{adhi} , the final standardisation would not be necessary; however, its application does not affect the outcome.

The choice of data input (frequencies x *vs.* proportions x') can sometimes matter: the numeric outcome can be very different, especially if the input samples comprise few observations. Theoretically, weighting frequencies emphasises our belief in individual observations at specific ages while weighting proportions emphasises our belief in sampled age distributions. Neither method yields inherently better results; however, if the original sampling methodology favoured sampling few fish from many tows rather than sampling many fish from few tows, then weighting frequencies probably makes more sense than weighting proportions. In this assessment, we weight age frequencies x.

The commercial age data suggest cohorts of better than average recruitment in 1968, 1981, and 1990 (Figure C.5). The Pacific Decadal Oscillation (PDO), where grey diagonal bands denote positive anomalies, appears to have limited influence. For the model analysis, years with fewer than three sampled trips were excluded: 1978, 1982, and 1984-1987 (Table C.5).

The West Coast Haida Gwaii Synoptic survey age data (Figure C.6, Table C.6) are only available for 2010, and appear to reflect the strong 1981 and 1990 cohorts obeserved in the commercial data. The Hecate Strait Synoptic survey (Figure C.7, Table C.7) provides two years of age data, again suggesting a strong 1990 cohort; however, very few specimens were aged. The Queen Charlotte Sound Synoptic survey (Figure C.8, Table C.8) provides three years of data that generally reflect the cohort patterns observed above. Finally, the age data from the West Coast Vancouver Island Synoptic survey (Figure C.9, Table C.9) are too sparse to comment on.

Figure C.5. Commercial Silvergray Rockfish proportions-at-age based on age frequencies weighted by trip catch within quarters and commercial catch within years. Diagonal shaded bands indicate cohorts that were born when the Pacific Decadal Oscillation was positive, potentially creating conditions in pelagic waters that foster productivity. Number of specimens aged are displayed along the bottom axis.

Table C.5. Commercial trips: number of sampled trips, Silvergray Rockfish catch (t) by trip and per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1978	0	0	1	1	0	0	9.25	3	61.4	103	680	278
1979	3	0	1	1	62.8	0	15.7	21.9	114	152	595	272
1980	1	2	1	0	13.6	26.1	11.3	0	69.1	311	507	235
1981	2	1	3	0	39.2	138	35.6	0	85.5	311	259	299
1982	0	0	2	0	0	0	56.7	0	189	367	261	255
1983	1	1	2	0	26.3	36.2	43.1	0	118	702	503	449
1984	0	0	0	1	0	0	0	18.1	199	1,031	701	578
1985	2	0	0	0	140	0	0	0	1,161	1,272	656	331
1986	0	0	0	2	0	0	0	33.9	1,146	1,161	353	681
1987	0	1	0	0	0	0.816	0	0	551	930	854	453
1988	1	0	1	1	20.9	0	8.84	9.07	680	856	1,108	867
1989	2	0	0	1	45.1	0	0	7.26	809	832	531	678
1990	12	5	2	0	121	26.8	9.07	0	672	844	454	234
1991	6	0	0	0	50.4	0	0	0	455	496	325	206

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Table C.5. Commercial trips: number of sampled trips, Silvergray Rockfish catch (t) by trip and per quarter.

Year	# Trips				Trip catch (t)				Commercial catch (t)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1992	2	3	2	1	7.26	11.8	5.44	2	339	608	447	294
1993	1	4	1	1	6.80	11.8	1.86	2.27	335	557	435	465
1994	4	5	6	8	21.1	28.2	39.7	105	565	816	617	866
1995	8	2	5	0	36.7	13.2	17.7	0	465	873	751	14.9
1996	0	4	2	4	0	17.5	1.68	43.8	165	340	320	418
1997	3	1	4	3	16.2	1.14	18.8	9.48	382	262	262	274
1998	14	3	2	5	70	1.61	9.06	18.4	439	318	422	252
1999	11	4	5	4	41.5	6.26	23.4	23.2	357	396	433	283
2000	11	5	7	5	61.2	22.1	16.2	11.6	517	391	344	192
2001	16	3	7	0	120	2.35	27	0	411	254	273	187
2002	7	2	5	6	19.6	2.13	11.3	3.48	369	201	371	258
2003	12	5	10	4	28.9	12.8	49.8	19.5	408	224	437	252
2004	9	10	7	10	22.9	23.8	12.6	27.3	384	290	377	255
2005	6	7	9	6	10.6	22.7	8.39	27.3	335	220	298	228
2006	1	9	0	4	0.401	16.8	0	1.56	398	412	376	151
2007	2	2	6	1	1.68	0.318	4.29	2.20	335	399	363	204
2009	3	2	2	3	9.47	1.07	1.17	14.4	437	477	326	196
2010	4	6	3	2	21	14.5	13.8	16.6	451	477	337	170
2011	4	4	2	0	34.6	1.67	4.62	0	447	400	386	186

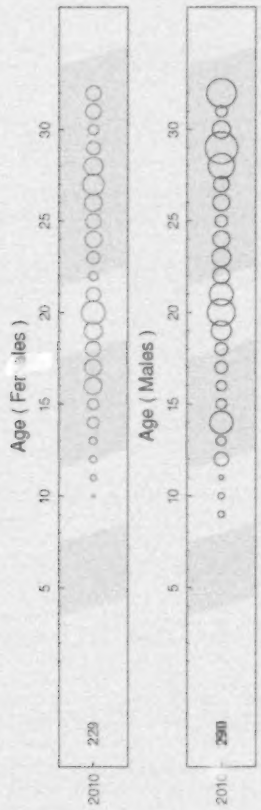

Figure C.6. West Coast Haida Gwaii Synoptic survey Silvergray Rockfish proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure C.5 for details on diagonal shaded bands and displayed numbers.

Table C.6. West Coast Haida Gwaii Synoptic survey: number of sampled tows and Silvergray Rockfish density per stratum (kg/km^2). Stratum areas: 151= 1104 km^2

Year	# Samples	Mean density (kg/km^2)
	151	151
2010	22	1,457

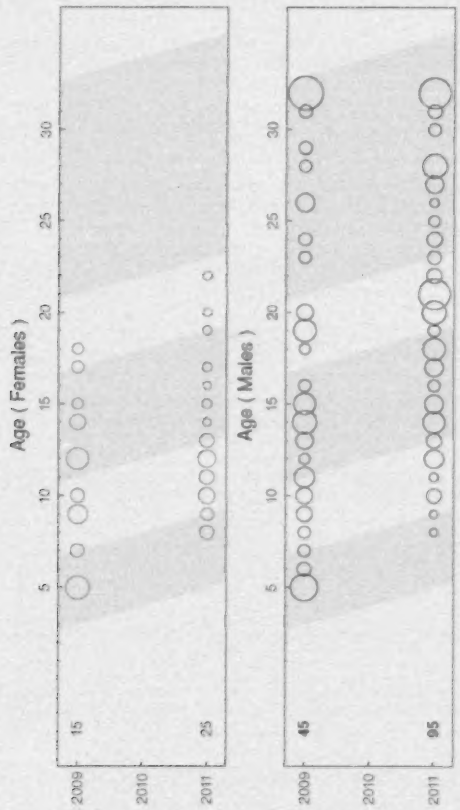

Figure C.7. Hecate Strait Synoptic survey Silvergray Rockfish proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure C.5 for details on diagonal shaded bands and displayed numbers.

Table C.7. Hecate Strait Synoptic survey: number of sampled tows and Silvergray Rockfish density per stratum (kg/km^2). Stratum areas: 073= 3064 km^2; 074= 2468 km^2

Year	# Samples		Mean density (kg/km^2)	
	073	074	073	074
2009	1	3	38.4	1,255
2011	2	4	828	1,430

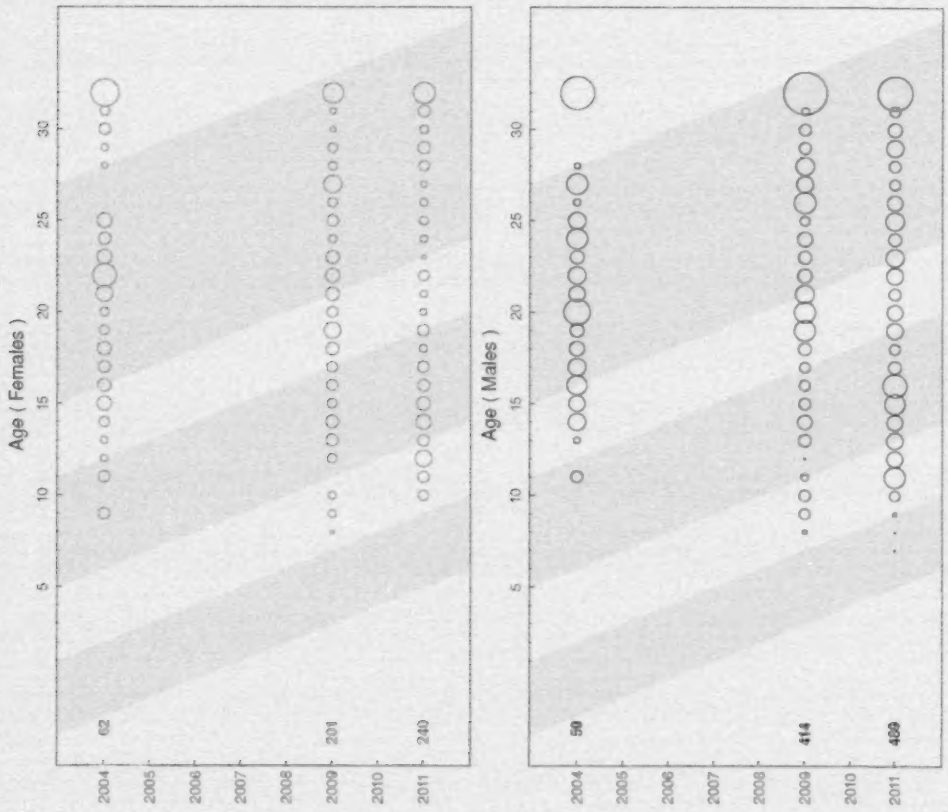

Figure C.8. Queen Charlotte Sound Synoptic survey Silvergray Rockfish proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure C.5 for details on diagonal shaded bands and displayed numbers.

Table C.8. Queen Charlotte Sound Synoptic survey: number of sampled tows and Silvergray Rockfish density per stratum (kg/km^2). Stratum areas: 018= 5092 km^2; 019= 5464 km^2; 022= 1840 km^2; 023= 4104 km^2; 024= 3760 km^2

Year	# Samples					Mean density (kg/km^2)				
	018	019	022	023	024	018	019	022	023	024
2004	0	0	0	3	0	0	0	0	2,522	0
2009	3	5	2	12	5	2,167	464	518	610	2,171
2011	1	6	1	15	9	255	886	907	1,236	856

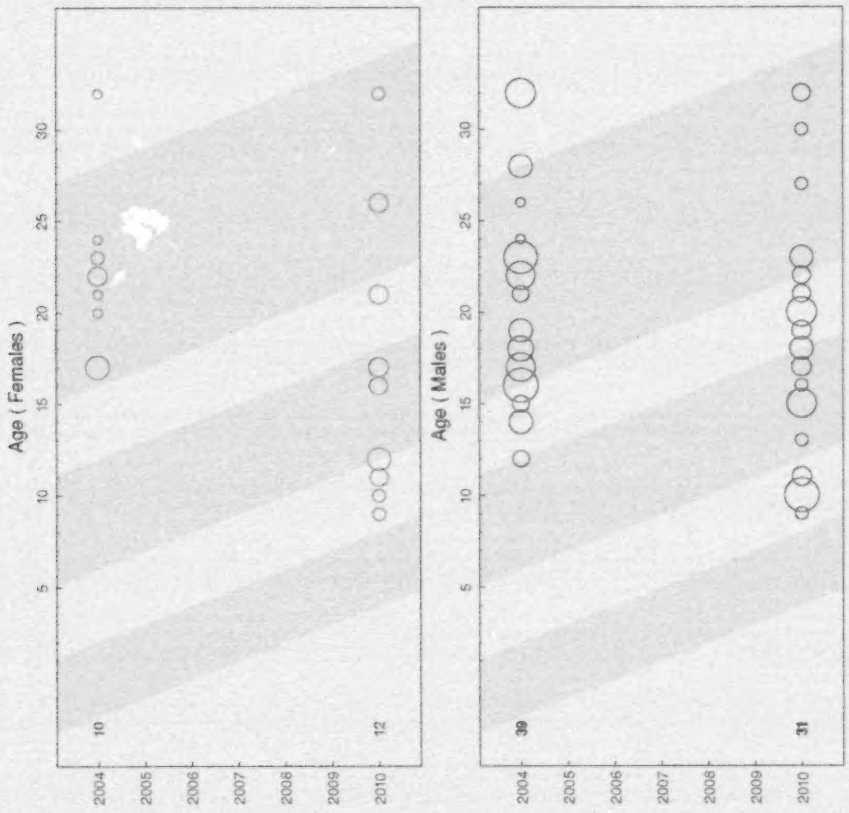

Figure C.9. West Coast Vancouver Island Synoptic survey Silvergray Rockfish proportions-at-age based on age frequencies weighted by sampled catch within strata and by total catch within survey. See Figure C.5 for details on diagonal shaded bands and displayed numbers.

Table C.9. West Coast Vancouver Island Synoptic survey: number of sampled tows and Silvergray Rockfish density per stratum (kg/km^2). Stratum areas: 066= 3880 km^2

Year	# Samples	Mean density (kg/km^2)
	066	066
2004	2	1,265
2010	2	1,332

APPENDIX D. MODEL EQUATIONS

D.1 INTRODUCTION

We used a sex-specific, age-structured model in a Bayesian framework. In particular, the model can simultaneously estimate the steepness of the stock-recruitment function and separate mortalities for males and females. This approach follows that used in our recent stock assessments of Pacific Ocean Perch (POP) in Queen Charlotte Sound, west coast Vancouver Island, and west coast Haida Gwaii (Edwards et al., 2012b, 2014b,a) and Yellowmouth Rockfish along the Pacific coast of Canada (Edwards et al., 2012a).

The model structure is the same as that used previously, and, as for the Yellowmouth Rockfish assessment and the two recent POP assessments, we used the new weighting scheme of Francis (2011) described below.

Implementation was done using a modified version of the Coleraine statistical catch-at-age software (Hilborn et al., 2003) called Awatea (A. Hicks, NOAA, pers. comm.). Awatea is a platform for implementing the AD (Automatic Differentiation) Model Builder software, which provides (a) maximum posterior density estimates using a function minimiser and automatic differentiation, and (b) an approximation of the posterior distribution of the parameters using the Markov Chain Monte Carlo (MCMC) method, specifically using the Hastings-Metropolis algorithm (Gelman et al., 2004).

Running of Awatea was streamlined using code we wrote in R (R Core Team, 2013), rather than the original Excel implementation. Figures and tables of output were automatically produced through R using code adapted from the R packages scape (Magnusson, 2009) and scapeMCMC (Magnusson and Stewart, 2007). We used the R software Sweave (Leisch, 2002) to automatically collate, via LATEX, the large amount of figures and tables into a single pdf file for each model run.

Below we describe details of the age-structured model, the Bayesian procedure, the reweighting scheme, the prior distributions, and the methods for calculating reference points and performing projections.

D.2 MODEL ASSUMPTIONS

The assumptions of the model are:

1. The stock coastwide was treated as a single stock.
2. Catches were taken by a single fishery, known without error, and occurred in the middle of the year.
3. A time-invariant Beverton-Holt stock-recruitment relationship was assumed, with log-normal error structure.
4. Selectivity was different between sexes and surveys and invariant over time. Selectivity parameters were estimated when ageing data were available.
5. Natural mortality was held invariant over time, and estimated independently for females and males.
6. Growth parameters were fixed and assumed to be invariant over time.
7. Maturity-at-age parameters for females were fixed and assumed to be invariant over time. Male maturity did not need to be considered, because it was assumed that there were always

sufficient mature males.

8. Recruitment at age 1 was 50% females and 50% males.
9. Fish ages determined using the surface ageing methods (before 1978) were too biased to use (Beamish, 1979). Ages determined using the otolith break-and-burn methodology (MacLellan, 1997) were aged without error.
10. Commercial samples of catch-at-age in a given year were assumed to be representative of the fishery if there were ≥4 samples.
11. Relative abundance indices were assumed to be proportional to the vulnerable biomass at the mid point of the year, after half of the catch and half of the natural mortality had been accounted for.
12. The age composition samples were assumed to come from the middle of the year after half of the catch and half of the natural mortality had been accounted for.

D.3 MODEL NOTATION AND EQUATIONS

The notation for the model is given in Table D.1, the model equations in Tables D.2 and D.3, and description of prior distributions for estimated parameters in Table D.4. The model description is divided into the deterministic components, stochastic components and Bayesian priors. Full details of notation and equations are given after the tables.

The main structure is that the deterministic components in Table D.2 can iteratively calculate numbers of fish in each age class (and of each sex) through time. The only requirements are the commercial catch data, weight-at-age and maturity data, and known fixed values for all parameters.

Given we do not have known fixed values for all parameters, we need to estimate many of them, and add stochasticity to recruitment. This is accomplished by the stochastic components given in Table D.3.

Incorporation of the prior distributions for estimated parameters gives the full Bayesian implementation, the goal of which is to minimise the objective function $f(\Theta)$ given by (D.23). This function is derived from the deterministic, stochastic and prior components of the model.

Table D.1 (continued overleaf). Notation for the catch-at-age model.

Symbol	Description and units
	Indices (all subscripts)
a	age class, where $a = 1, 2, 3, ...A$, and $A = 32$ is the accumulator age class
t	model year, where $t = 1, 2, 3, ...T$, corresponds to actual years 1940, 1941, 1942, ..., 2014, and $t = 0$ represents unfished equilibrium conditions
g	index for certain data: 1 - West Coast Haida Gwaii synoptic survey series 2 - Hecate Strait synoptic survey series 3 - Queen Charlotte Sound syoptic survey series 4 - West Coast Vancouver Island synoptic survey series 5 - GB Reed historical survey series 6 - National Marine Fisheries Service Triennial survery series 7 - commercial trawl data
s	sex, 1 = females, 2 = males
	Index ranges
A	accumulator age-class, $A = 32$
T	number of model years, $T = 75$
$\mathbf{T}_g$	sets of model years for survey abundance indices from series g, $g = 1, ..., 6$, listed here for clarity as actual years (subtract 1939 to give model year t): $\mathbf{T}_1$ = {1997, 2006, 2007, 2008, 2010, 2012} $\mathbf{T}_2$ = {2005, 2007, 2009, 2011, 2013} $\mathbf{T}_3$ = {2003, 2004, 2005, 2007, 2009, 2011, 2013} $\mathbf{T}_4$ = {2004, 2006, 2008, 2010, 2012} $\mathbf{T}_5$ = {1967, 1969, 1971, 1973, 1976, 1977, 1984} $\mathbf{T}_6$ = {1980, 1983, 1989, 1992, 1995, 1998, 2001}
$\mathbf{U}_g$	sets of model years with proportion-at-age data, $g = 1, ..., 4$ (listed here as actual years): $\mathbf{U}_1$ = {1997, 2010} $\mathbf{U}_2$ = {2009, 2011} $\mathbf{U}_3$ = {2004, 2009, 2011} $\mathbf{U}_4$ = {2004, 2010} $\mathbf{U}_7$ = {1979,...,1981, 1983, 1990,...,2007, 2009,...,2011}
	Data and fixed parameters
p_{atgs}	observed weighted proportion of fish from series g in each year $t \in \mathbf{U}_g$ that are age-class a and sex s; so $\sum_{a=1}^{A}\sum_{s=1}^{2} p_{atgs} = 1$ for each $t \in \mathbf{U}_g$, $g = 1, ..., 4$
n_{tg}	assumed sample size that yields corresponding p_{atgs}
C_t	observed catch biomass in year $t = 1, 2, ..., T-1$, tonnes
w_{as}	average weight of individual of age-class a of sex s from fixed parameters, kg
m_a	proportion of age-class a females that are mature, fixed from data
I_{tg}	biomass estimates from surveys $g = 1, ..., 6$, for year $t \in \mathbf{T}_g$, tonnes
κ_{tg}	standard deviation of I_{tg}
σ_R	standard deviation parameter for recruitment process error, $\sigma_R = 0.6$

Table D.1 (cont.). Notation for the catch-at-age model.

Symbol	Description, with fixed values and/or units where appropriate
	Estimated parameters
Θ	set of estimated parameters
R_0	virgin recruitment of age-1 fish (numbers of fish, 1000s)
M_s	natural mortality rate for sex s, $s = 1, 2$
h	steepness parameter for Beverton-Holt recruitment
q_g	catchability for survey series $g = 1, ..., 6$
μ_g	age of full selectivity for females for series $g = 1, ..., 7$
Δ_g	shift in vulnerability for males for series $g = 1, ..., 7$
v_{gL}	variance parameter for left limb of selectivity curve for series $g = 1, ..., 7$
s_{ags}	selectivity for age-class a, series $g = 1, ..., 7$, and sex s, calculated from the parameters μ_g, Δ_g and v_{gL}
α, β	alternative formulation of recruitment: $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/4hR_0$
$\hat{x}$	estimated value of observed data x
	Derived states
N_{ats}	number of age-class a fish of sex s at the start of year t, 1000s
u_{ats}	proportion of age-class a and sex s fish in year t that are caught
u_t	ratio of total catch to vulnerable biomass in the middle of the year (exploitation rate)
B_t	spawning biomass (mature females) at the start of year t, $t = 1, 2, 3, ..., T$; tonnes
B_0	virgin spawning biomass (mature females) at the start of year 0, tonnes
R_t	recruitment of age-1 fish in year t, $t = 1, 2, ..., T-1$, numbers of fish, 1000s
V_t	vulnerable biomass (males and females) in the middle of year t, $t = 1, 2, 3, ..., T$; tonnes
	Deviations and likelihood components
ϵ_t	Recruitment deviations arising from process error
$\log L_1(\Theta\|\{\epsilon_t\})$	log-likelihood component related to recruitment residuals
$\log L_2(\Theta\|\{\tilde{p}_{atgs}\})$	log-likelihood component related to estimated proportions-at-age
$\log L_3(\Theta\|\{\tilde{I}_{tg}\})$	log-likelihood component related to estimated survey biomass indices
$\log L(\Theta)$	total log-likelihood
	Prior distributions and objective function
$\pi_j(\Theta)$	Prior distribution for parameter j
$\pi(\Theta)$	Joint prior distribution for all estimated parameters
$f(\Theta)$	Objective function to be minimised

Table D.2. Deterministic components (continued overleaf). Using the catch, weight-at-age and maturity data, with fixed values for all parameters, the initial conditions are calculated from (D.4)-(D.6), and then state dynamics are iteratively calculated through time using the main equations (D.1)-(D.3), selectivity functions (D.7) and (D.8), and the derived states (D.9)-(D.13). Estimated observations for survey biomass indices and proportions-at-age can then be calculated using (D.14) and (D.15). In Table D.3, the estimated observations of these are compared to data.

State dynamics ($2 \leq t \leq T$, $s = 1, 2$)

$$N_{1ts} = 0.5 R_t \tag{D.1}$$

$$N_{ats} = e^{-M_s}(1 - u_{a-1,t-1,s}) N_{a-1,t-1,s}; \quad 2 \leq a \leq A-1 \tag{D.2}$$

$$N_{Ats} = e^{-M_s}(1 - u_{A-1,t-1,s}) N_{A-1,t-1,s} + e^{-M_s}(1 - u_{A,t-1,s}) N_{A,t-1,s} \tag{D.3}$$

Initial conditions ($t = 1$)

$$N_{a1s} = 0.5 R_0 e^{-M_s(a-1)}; \quad 1 \leq a \leq A-1, \; s = 1, 2 \tag{D.4}$$

$$N_{A1s} = 0.5 R_0 \frac{e^{-M_s(A-1)}}{1 - e^{-M_s}}; \quad s = 1, 2 \tag{D.5}$$

$$B_0 = B_1 = \sum_{a=1}^{A} w_{a1} m_a N_{a11} \tag{D.6}$$

Selectivities ($g = 1, ..., 7$)

$$s_{ag1} = \begin{cases} e^{-(a-\mu_g)^2/v_{gL}}, & a \leq \mu_g \\ 1, & a > \mu_g \end{cases} \tag{D.7}$$

$$s_{ag2} = \begin{cases} e^{-(a-\mu_g-\Delta_g)^2/v_{gL}}, & a \leq \mu_g + \Delta_g \\ 1, & a > \mu_g + \Delta_g \end{cases} \tag{D.8}$$

Derived states ($1 \leq t \leq T-1$)

$$B_t = \sum_{a=1}^{A} w_{a1} m_a N_{at1} \tag{D.9}$$

$$R_t = \frac{4hR_0 B_{t-1}}{(1-h)B_0 + (5h-1)B_{t-1}} \quad \left(\equiv \frac{B_{t-1}}{\alpha + \beta B_{t-1}} \right) \tag{D.10}$$

$$V_t = \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2} w_{as} s_{a7s} N_{ats} \tag{D.11}$$

$$u_t = \frac{C_t}{V_t} \tag{D.12}$$

$$u_{ats} = s_{a7s} u_t; \quad 1 \leq a \leq A, \; s = 1, 2 \tag{D.13}$$

Estimated observations

$$\hat{I}_{tg} = q_g \sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) w_{as} s_{ags} N_{ats}; \quad t \in \mathbf{T}_g, \; g = 1, 2, 3 \tag{D.14}$$

$$\hat{p}_{atgs} = \frac{e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}{\sum_{s=1}^{2} \sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2) s_{ags} N_{ats}}; \quad 1 \leq a \leq A, \; t \in \mathbf{U}_g, \; g = 1, 4, \; s = 1, 2 \tag{D.15}$$

Table D.3. Calculation of likelihood function $L(\Theta)$ for stochastic components of the model in Table D.2, and resulting objective function $f(\Theta)$ to be minimised.

Estimated parameters

$$\Theta = \{R_0; M_{1,2}; h; q_{1,\ldots,6}; \mu_{1,\ldots,4,7}; \Delta_{1,\ldots,4,7}; v_{1,\ldots,4,7L}\} \tag{D.16}$$

Recruitment deviations

$$\epsilon_t = \log R_t - \log B_{t-1} + \log(\alpha + \beta B_{t-1}) + \sigma_R^2/2; \;\; 1 \le t \le T-1 \tag{D.17}$$

Log-likelihood functions

$$\log L_1(\Theta|\{\epsilon_t\}) = -\frac{T}{2}\log 2\pi - T\log\sigma_R - \frac{1}{2\sigma_R^2}\sum_{t=1}^{T-1}\epsilon_t^2 \tag{D.18}$$

$$\begin{aligned}\log L_2(\Theta|\{\widehat{p}_{atgs}\}) = &-\frac{1}{2}\sum_{g=1,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right] \\ &+ \sum_{g=1,4}\sum_{a=1}^{A}\sum_{t\in\mathbf{U}_g}\sum_{s=1}^{2}\log\left[\exp\left\{\frac{-(p_{atgs}-\widehat{p}_{atgs})^2\, n_{tg}}{2\left(p_{atgs}(1-p_{atgs}) + \frac{1}{10A}\right)}\right\} + \frac{1}{100}\right]\end{aligned} \tag{D.19}$$

$$\log L_3(\Theta|\{\widehat{I}_{tg}\}) = \sum_{g=1}^{3}\sum_{t\in\mathbf{T}_g}\left[-\frac{1}{2}\log 2\pi - \log\kappa_{tg} - \frac{(\log I_{tg} - \log\widehat{I}_{tg})^2}{2\kappa_{tg}^2}\right] \tag{D.20}$$

$$\log L(\Theta) = \sum_{i=1}^{3}\log L_i(\Theta|\cdot) \tag{D.21}$$

Joint prior distribution and objective function

$$\log(\pi(\Theta)) = \sum_j \log(\pi_j(\Theta)) \tag{D.22}$$

$$f(\Theta) = -\log L(\Theta) - \log(\pi(\Theta)) \tag{D.23}$$

Table D.4. Details for estimation of parameters, including prior distributions with corresponding means and standard deviations, bounds between which parameters are constrained, and initial values to start the minimisation procedure for the MPD (mode of the posterior density) calculations. For uniform prior distributions, the bounds completely parameterise the prior. The resulting non-uniform prior probability density functions are the $\pi_j(\Theta)$ functions that contribute to the joint prior distribution in (D.22).

Parameter	Prior distribution	Mean, standard deviation	Bounds	Initial value
R_0	uniform	–	[1, 100,000]	3,000
M_1, M_2	normal	0.06, 0.006	[0.01, 0.12]	0.06
h	beta	4.574, 2.212	[0.2, 0.999]	0.674
$\log q_{1,\ldots,6}$	uniform	0, 0.6	[-5, 5]	0
$\mu_{1,2}$	normal	10.8, 3.24	[5, 32]	10.8
μ_3	normal	13.3, 4.0	[5, 32]	13.3
μ_4	normal	15.4, 4.62	[5, 32]	15.4
μ_7	uniform	10.5, 3.15	[5, 32]	10.5
$\log v_{1,2L}$	normal	2.08, 0.62	[-15, 15]	2.08
$\log v_{3L}$	normal	3.3, 1.0	[-15, 15]	3.3
$\log v_{4L}$	normal	3.44, 1.03	[-15, 15]	3.44
$\log v_{7L}$	uniform	1.52, 0.46	[-15, 15]	1.52
$\Delta_{1,\ldots,4}$	normal	0.22, 0.066	[-6, 6]	0.22
Δ_7	uniform	0, 0.3	[-6, 6]	0

D.4 DESCRIPTION OF DETERMINISTIC COMPONENTS

Notation (Table D.1) and set up of the deterministic components (Table D.2) are now described.

D.4.1 Age classes

Index (subscript) a represents age classes, going from 1 to the accumulator age class, A, of 32. Age class $a = 5$, for example, represents fish aged 4-5 years (which is the usual, though not universal, convention, Caswell 2001), and so an age-class 1 fish was born the previous year. The variable N_{ats} is the number of age-class a fish of sex s at the *start* of year t, so the model is run to year T which corresponds to 2014.

D.4.2 Years

Index t represents model years, going from 1 to $T = 75$, and $t = 0$ represents unfished equilibrium conditions. The actual year corresponding to $t = 1$ is 1940, and so model year $T = 75$ corresponds to 2014. Catch data for the whole of 2013 are not available (since the assessment model is being run in September 2013), and so the catch for 2013 was set to that for 2012.

D.4.3 Survey data

Data from six survey series were used, as described in detail in Appendix C. Here, subscript $g = 1$ corresponds to the West Coast Haida Gwaii synoptic survey series, $g = 2$ to the Hecate Strait synoptic survey, $g = 3$ to the Queen Charlotte Sound synoptic survey, $g = 4$ to the West Coast Vancouver Island synoptic survey, $g = 5$ to the GB Reed historical survey series, and $g = 6$ to the United States National Marine Fisheries Service Triennial survery series. The years for which data are available for each survey are given in Table D.1; $\mathbf{T}_g$ corresponds to years for the survey biomass estimates I_{tg} (and corresponding standard deviations κ_{tg}), and $\mathbf{U}_g$ corresponds to years for proportion-at-age data p_{atgs} (with assumed sample sizes n_{tg}). Note that there are no $\mathbf{U}_5$ or $\mathbf{U}_6$ because there are no age data for those surveys.

D.4.4 Commercial data

As described in Appendix A, the commercial catch has been reconstructed back to 1918. Given the negligible catches in the early years, the model was started in 1940, and catches prior to 1940 were not considered. The time series for catches is denoted C_t. The set $\mathbf{U}_7$ (Table D.1) gives the years of available ageing data from the commercial fishery. The proportions-at-age values are given by p_{atgs} with assumed sample size n_{tg}, where $g = 7$ (to correspond to the commercial data). These proportions are the weighted proportions calculated using the stratified weighting scheme described in Appendix C, that adjusts for unequal sampling effort across temporal and spatial strata.

D.4.5 Sex

A two-sex model was used, with subscript $s = 1$ for females and $s = 2$ for males. Ageing data were partitioned by sex, as were the weights-at-age inputs. Selectivities and natural mortality were estimated by sex.

D.4.6 Weights-at-age

The weights-at-age w_{as} are assumed fixed over time and based on the biological data.

D.4.7 Maturity of females

The proportion of age-class a females that are mature is m_a, and is assumed fix over time; see Appendix C for details.

D.4.8 State dynamics

The crux of the model is the set of dynamical equations (D.1)-(D.3) for the estimated number N_{ats} of age-class a fish of sex s at the start of year t. Equation (D.1) states that half of new recruits are males and half are females. Equation (D.2) calculates the numbers of fish in each age class (and of each sex) that survive to the following year, where u_{ats} represents the proportion caught by the commercial fishery, and e^{-M_s} accounts for natural mortality. Equation (D.3) is for the accumulator age class A, whereby survivors from this class remain in this class the following year.

Natural mortality M_s was determined separately for males and females. It enters the equations in the form e^{-M_s} as the proportion of unfished individuals that survive the year.

D.4.9 Initial conditions

An unfished equilibrium situation at the beginning of the reconstruction is assumed, because there is no evidence of significant removals prior to 1940, and 1940 predates significant removals by about 15 years (Appendix A). The initial conditions (D.4) and (D.5) are obtained by setting $R_t = R_0$ (virgin recruitment), $N_{ats} = N_{a1s}$ (equilibrium condition) and $u_{ats} = 0$ (no fishing) into (D.1)-(D.3). The virgin spawning biomass B_0 is then obtained from (D.9).

D.4.10 Selectivities

Separate selectivities were modelled for the commercial catch data and for each survey series. A half-Gaussian formulation was used, as given in (D.7) and (D.8), to give selectivities s_{ags} (note that the subscript $\cdot_s$ always represents the index for sex, whereas $s_{\cdots}$ always represents selectivity). This permits an increase in selectivity up to the age of full selection (μ_g for females). Given there was no evidence to suggest a dome-shaped function, it was assumed that fish older than μ_g remain fully selected. The rate of ascent of the left limb is controlled by the parameter v_{gL} for females. For males, the same function is used except that the age of full selection is shifted by an amount Δ_g, see (D.8).

D.4.11 Derived states

The spawning biomass (biomass of mature females, in tonnes) B_t at the start of year t is calculated in (D.9) by multiplying the numbers of females N_{at1} by the proportion that are mature (m_a), and converting to biomass by multiplying by the weights-at-age w_{a1}.

Equation (D.13) calculates, for year t, the proportion u_{ats} of age-class a and sex s fish that are caught. This requires the commercial selectivities s_{a7s} and the ratio u_t, which equation (D.12) shows is the ratio of total catch to vulnerable biomass in the middle of the year, V_t, given by equation (D.11). So (D.12) calculates the proportion of the vulnerable biomass that is caught, and (D.13) partitions this out by sex and age.

D.4.12 Stock-recruitment function

A Beverton-Holt recruitment function is used, parameterised in terms of steepness, h, which is the proportion of the long-term unfished recruitment obtained when the stock abundance is reduced to 20% of the virgin level (Mace and Doonan, 1988; Michielsens and McAllister, 2004). This was done so that a prior for h could be taken from Forrest et al. (2010). The formulation shown in (D.10) comes from substituting $\alpha = (1-h)B_0/(4hR_0)$ and $\beta = (5h-1)/4hR_0$ into the Beverton-Holt equation $R_t = B_{t-1}/(\alpha + \beta B_{t-1})$, where α and β are from the standard formulation given in the Coleraine manual (Hilborn et al. 2003; see also Michielsens and McAllister 2004), R_0 is the virgin recruitment, R_t is the recruitment in year t, B_t is the spawning biomass at the start of year t and B_0 is the virgin spawning biomass.

D.4.13 Estimates of observed data

The model estimates of the survey biomass indices I_{tg} are denoted $\widehat{I}_{tg}$ and are calculated in (D.14). The estimated numbers N_{ats} are multiplied by the natural mortality term $e^{-M_s/2}$ (that accounts for half of the annual natural mortality), the term $1 - u_{ats}/2$ (that accounts for half of the commercial catch), weights-at-age w_{as} (to convert to biomass) and selectivity s_{ags}. The sum (over ages and sexes) is then multiplied by the catchability parameter q_g to give the model biomass estimate $\widehat{I}_{tg}$. A 0.001 coefficient in (D.14) is not needed to convert kg into tonnes, because N_{ats} is in 1000s of fish (true also for (D.6) and (D.9)).

The estimated proportions-at-age $\widehat{p}_{atgs}$ are calculated in (D.15). For a particular year and gear type, the product $e^{-M_s/2}(1 - u_{ats}/2)s_{ags}N_{ats}$ gives the relative expected numbers of fish caught for each combination of age and sex. Division by $\sum_{s=1}^{2}\sum_{a=1}^{A} e^{-M_s/2}(1 - u_{ats}/2)s_{ags}N_{ats}$ converts these to estimated proportions for each age-sex combination, such that $\sum_{s=1}^{2}\sum_{a=1}^{A}\widehat{p}_{atgs} = 1$.

D.5 DESCRIPTION OF STOCHASTIC COMPONENTS

D.5.1 Parameters

The set Θ gives the parameters that are estimated. The estimation procedure is described in the Bayesian Computations section below.

D.5.2 Recruitment deviations

For recruitment, a log-normal process error is assumed, such that the stochastic version of the deterministic stock-recruitment function (D.10) is

$$R_t = \frac{B_{t-1}}{\alpha + \beta B_{t-1}} e^{\epsilon_t - \sigma_R^2/2} \tag{D.24}$$

where $\epsilon_t \sim \text{Normal}(0, \sigma_R^2)$, and the bias-correction term $-\sigma_R^2/2$ term in (D.24) ensures that the mean of the recruitment deviations equals 0. This then gives the recruitment deviation equation (D.17) and log-likelihood function (D.18). The value of σ_R was fixed at 0.6, which is typical for marine *redfish* (Mertz and Myers, 1996).

D.5.3 Log-likelihood functions

The log-likelihood function (D.19) arises from comparing the estimated proportions-at-age with the data. It is the Coleraine (Hilborn et al., 2003) modification of the Fournier et al. (1990, 1998) robust likelihood equation. The Coleraine formulation replaces the expected proportions $\widehat{p}_{atgs}$ from the Fournier et al. (1990, 1998) formulation with the observed proportions p_{atgs}, except in the $(p_{atgs} - \widehat{p}_{atgs})^2$ term (Bull et al., 2005).

The $1/(10A)$ term in (D.19) reduces the weight of proportions that are close to or equal zero. The $1/100$ term reduces the weight of large residuals $(p_{atgs} - \widehat{p}_{atgs})$. The net effect (Stanley *et al.* 2009) is that residuals larger than three standard deviations from the fitted proportion are treated roughly as $3(p_{atgs}(1 - p_{atgs}))^{1/2}$.

Lognormal error is assumed for the survey indices, resulting in the log-likelihood equation (D.20). The total log-likelihood $\log L(\Theta)$ is then the sum of the likelihood components – see (D.21).

D.6 BAYESIAN COMPUTATIONS

Estimation of parameters compares the estimated (model-based) observations of survey biomass indices and proportions-at-age with the data, and minimises the recruitment deviations. This is done by minimising the objective function $f(\Theta)$, which equation (D.23) shows is the negative of the sum of the total log-likelihood function and the logarithm of the joint prior distribution, given by (D.22).

The procedure for the Bayesian computations is as follows:

1. minimise the objective function $f(\Theta)$ to give estimates of the mode of the posterior density (MPD) for each parameter
    - this is done in phases
    - a reweighting procedure is performed
2. generate samples from the joint posterior distributions of the parameters using Monte Carlo Markov Chain (MCMC) procedure, starting the chains from the MPD estimates.

D.6.1 Phases

The MPD estimates were obtained by minimising the objective function $f(\Theta)$, from the stochastic (non-Bayesian version) of the model. The resulting estimates were then used to initiate the chains for the MCMC procedure for the full Bayesian model.

Simultaneously estimating all the estimable parameters straight away for complex nonlinear models is ill advised, and so ADMB allows some of the estimable parameters to be kept fixed during the initial part of the optimisation process ADMB Project (2009). Some parameters are estimated in phase 1, then some further ones in phase 2, and so on. The order used here was:

phase 1: virgin recruitment R_0 and survey catchabilities $q_{1,...,6}$;

phase 2: recruitment deviations ϵ_t (held at 0 in phase 1);

phase 3: age of full selectivity for females $\mu_{1,...,4,7}$;

phase 4: natural mortality $M_{1,2}$ and selectivity parameters Δ_g, v_{gL} for $g = 1, ..., 4, 7$;

phase 5: steepness h.

D.6.2 Reweighting

Given that sample sizes are not comparable between different types of data, a procedure that adjusts the relative weights between data sources is required. The QCS POP assessment (Edwards et al., 2012b) used an iterative reweighting scheme based on adjusting the standard deviation of normal residuals (SDNRs) of data sets until these standard deviations were approximately 1. This procedure did not perform well for the Yellowmouth Rockfish assessment (Edwards et al., 2012a), leading to spurious cohorts; therefore, the Yellowmouth assessment used the reweighting scheme proposed by Francis (2011). In this assessment, we use the latter scheme – weighting age sample size by mean age (see below).

For abundance data such as survey indices, Francis (2011) recommends reweighting observed

coefficients of variation, c_0, by first adding process error $c_p = 0.2$ to give a reweighted coefficient of variation

$$c_1 = \sqrt{c_0^2 + c_p^2}\,. \tag{D.25}$$

For each survey index, I_{tg} ($g = 1, ..., 4; t \in \mathbf{T}_g$), the associated standard deviation is κ_{tg}. The associated coefficient of variation is therefore κ_{tg}/I_{tg}, which is used in (D.25) to determine the reweighted coefficient of variation associated with κ_{tg}. This reweighted coefficient of variation is then converted back to a standard deviation, which is used as the reweighted standard deviation κ_{tg} in the likelihood function (D.20). In this assessment, we manually adjusted the CV process error at each reweight until the surveys attained SDNR values between 0.8 and 1.2. This was achieved after three reweights. We placed an upper limit of 0.4 to the added process error to avoid completely devaluing the survey.

Francis (2011) maintains that correlation effects are usually strong in age-composition data. Each age-composition data set has a sample size n_{tg} ($g = 1, 4$, $t \in \mathbf{U}_g$), which is typically in the range 3-20. Equation (T3.4) of Francis (2011) is used to iteratively reweight the sample size as

$$n_{tg}^{(r)} = W_g^{(r)} n_{tg}^{(r-1)} \tag{D.26}$$

where $r = 1, 2, 3, ..., N$ represents the reweighting iteration, $n_{tg}^{(r)}$ is the effective sample size for reweighting r, $W_g^{(r)}$ is the weight applied to obtain reweighting r, and $n_{tg}^{(0)} = n_{tg}$. So a single weight $W_g^{(r)}$ is calculated for each series $g = 1, ..., 4, 7$ for reweighting r.

The Francis (2011) weight $W_g^{(r)}$ given to each data set takes into account deviations from the mean weight for each year, rather than the scheme used for the QCS POP assessment (Edwards et al., 2012b) that considered deviations from each proportion-at-age value. It is given by equation (TA1.8) of Francis (2011):

$$W_g^{(r)} = \left\{ \mathrm{Var}_t \left[\frac{\overline{O}_{gt} - \overline{E}_{gt}}{\sqrt{\theta_{gt}/n_{tg}^{(r-1)}}} \right] \right\}^{-1} \tag{D.27}$$

where the observed mean age, the expected mean age and the variance of the expected age distribution are, respectively,

$$\overline{O}_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a p_{atgs} \tag{D.28}$$

$$\overline{E}_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a \widehat{p}_{atgs} \tag{D.29}$$

$$\theta_{gt} = \sum_{a=1}^{A} \sum_{s=1}^{2} a^2 \widehat{p}_{atgs} - \overline{E}_{gt}^2 \tag{D.30}$$

and Var_t is the usual finite-sample variance function applied over the index t. For the Yellowmouth Rockfish assessment Edwards et al. (2012a) we used this approach iteratively with $r = 1, 2, ..., 6$, but found that reweightings after the first ($r = 1$) had only a marginal effect; the reported results for this assessment were based on the third reweighting.

D.6.3 Prior distributions

Descriptions of the prior distributions for the 26 estimated parameters (without including recruitment deviations) are given in Table D.4 and in Table 1A and Table 1B in the Main Document. The resulting probability density functions give the $\pi_j(\Theta)$, whose logarithms are then summed in (D.22) to give the joint prior distribution $\pi(\Theta)$. Since uniform priors are, by definition, constant across their bounded range (and zero outside), their contributions to the objective function can be ignored. Thus, in the calculation (D.22) of the joint prior distribution $\pi(\Theta)$, only those priors that are not uniform need to be considered in the summation.

A uniform prior over a large range was used for R_0. The priors for female and male natural mortality, M_1 and M_2 respectively, were based on previous assessments of Silvergray that assume M = 0.06 (Stanley and Kronlund, 2000; Stanley and Olsen, 2002), which we use as the mean and assume a 10% CV (Table D.4).

For steepness, h, the same prior was used as for the QCS POP assessment (Edwards et al., 2012b) – a beta distribution with values fitted to the posterior distribution for rockfish calculated by Forrest et al. (2010). Uniform priors on a logarithmic scale were used for the catchability parameters q_g.

Selectivity was estimated for the four surveys with age composition data: west coast Haida Gwaii, Hecate Strait, Queen Charlotte Sound and west coast Vancouver Island synoptic survey series ($g = 1$ to $g = 4$). Informative priors were developed for the three selectivity parameters for each of these surveys, $\mu_{1,\ldots,4}$, $\Delta_{1,\ldots,4}$, and $v_{1,\ldots,4L}$, based on the median values for the same parameters from the matching base case POP assessments (Edwards et al., 2012b, 2014b,a). The parameter estimates from the west coast Haida Gwaii synoptic survey were used for the Hecate Strait survey because this survey was not used in these POP assessments. Normal distributions were assumed for the priors, with the means taken from the median values of the posterior distributions and with the standard deviations set to give coefficients of variation of 0.3.

No age data were available for the other two survey series, the GB Reed historical survey series and the National Marine Fisheries Service triennial survey series, so the three selectivity parameters for these surveys were fixed rather than estimated. The fixed values used for these selectivities were the posterior medians from the same survey in the 5ABC base case POP stock assessment (for the GB Reed survey series) and from the WCVI synoptic survey from the 3CD base case POP stock assessment (for the Triennial survey series).

For the commercial selectivity ($g = 7$) the priors for the three parameters were uniform (non-informative) distributions with starting values based on the median values of the posterior disributions for the 'Estimate M and h' model run of the 5ABC POP stock assessment.

D.6.4 MCMC properties

The MCMC procedure started the search from the MPD values and performed 10,000,000 iterations, sampling every 10,000$^{\text{th}}$ for 1,000 samples, which were used with no burn-in period (because the MCMC searches started from the MPD values).

D.7 REFERENCES POINTS, PROJECTIONS AND ADVICE TO MANAGERS

Advice to managers is given with respect to two sets of reference points or reference criteria. The first set consists of the provisional reference points of the DFO Precautionary Approach (DFO, 2006), namely $0.4B_{\mathrm{MSY}}$ and $0.8B_{\mathrm{MSY}}$ (and we also provide B_{MSY}); B_{MSY} is the estimated equilibrium spawning biomass at the maximum sustainable yield (MSY). The second set of reference points are $0.2B_0$ and $0.4B_0$, where B_0 is the estimated unfished equilibrium spawning biomass. See main text for further discussion.

To estimate B_{MSY}, the model was projected forward across a range (0 to 0.3 incremented by 0.001) of constant harvest rates (u_t), for a maximum of 15,000 years until equilibrium was reached (with a tolerance of 0.01 t). The MSY is the largest of the equilibrium yields, and the associated exploitation rate is then u_{MSY} and the associated spawning biomass is B_{MSY}. This calculation was done for each of the 1,000 MCMC samples, resulting in marginal posterior distributions for MSY, u_{MSY} and B_{MSY}.

The probability P($B_{2014} > 0.4B_{\mathrm{MSY}}$) is then calculated as the proportion of the 1,000 MCMC samples for which $B_{2014} > 0.4B_{\mathrm{MSY}}$ (and similarly for the other reference points).

Projections were made for 10 years starting with the biomass and age structure calculated for the start of 2014. A range of constant catch strategies were used, from 0-3,000 t (the average catch from 2009-2013 was 1431 t). For each strategy, projections were performed for each of the 1,000 MCMC samples (resulting in posterior distributions of future spawning biomass). Recruitments were randomly calculated using (D.24) (i.e. based on lognormal recruitment deviations from the estimated stock-recruitment curve), using randomly generated values of $\epsilon_t \sim \mathrm{Normal}(0, \sigma_R^2)$. For each of the 1,000 MCMC samples a time series of $\{\epsilon_t\}$ was generated. For each MCMC sample, the same time series of $\{\epsilon_t\}$ was used for each catch strategy (so that, for a given MCMC sample, all catch strategies experience the same recruitment stochasticity).

APPENDIX E. MODEL RESULTS

E.1 INTRODUCTION

This Appendix describes the results from the mode of the posterior distribution (MPD) (to compare model estimates to observations), diagnostics of the Markov chain Monte Carlo (MCMC) results, and the MCMC results for the estimated parameters. The final advice and major outputs are obtained from the MCMC results. Estimates of major quantities and advice to management (such as decision tables) are also presented in the main text.

E.2 MODE OF THE POSTERIOR DISTRIBUTION (MPD) RESULTS

Awatea first determines the MPD for each estimated parameter. These are then used as the starting points for the MCMC simulations. The MPD fits are shown for the survey indices (Figure E.1), the commercial catch-at-age data (as overlaid age structures in Figures E.2 and E.3), the West Coast Haida Gwaii (WCHG) synoptic survey (Figure E.4), the Hecate Strait (HS) synoptic survey (Figure E.5), the Queen Charlotte Sound (QCS) synoptic survey (Figure E.6), and the West Coast Vancouver Island (WCVI) synoptic survey series age data (Figure E.7). The results are sensible and are able to capture the main features of the data sets fairly well. There appears to be relative consistency between the available data sources.

Residuals to the MPD model fits are provided for the six survey indices (Figures E.8 to E.13), and the five sets of age data (Figures E.14 to E.18). These further suggest that the model fits are consistent with the data, as do the mean ages for the two sets of age data (Figure E.19).

Figure E.20 shows the resulting stock-recruitment function and the MPD values of recruitment over time (though see Figure E.37 for the MCMC values of recruitment). Figure E.21 shows that the recruitment deviations display little trend over time, and that the auto-correlation function of the deviations appears satisfactory. Figure E.22 gives the MPD fits for the selectivities, together with ogive for female maturity. Figure E.23 gives the exploitation over time. The values of the log-likelihood and objective functions for the MPD fits are given in Table E.1.

E.3 BAYESIAN MCMC RESULTS

The MCMC procedure performed 10,000,000 iterations, sampling every 10,000$^{\text{th}}$ to give 1,000 MCMC samples. The 1,000 samples were used with no burn-in period (because the MCMC searches started from the MPD values). The quantiles (0.05, 0.50, 0.95) for estimated parameters and derived quantities appear in Tables E.2 and E.3. In particular, the current year median estimate of B_{2014} is 19,803 t. The median depletion estimate B_{2014}/B_0 is 0.559.

MCMC traces show acceptable convergence properties (no trend with increasing sample number) for the estimated parameters (Figure E.24), as does a diagnostic analysis that splits the samples into three segments (Figure E.25). Some of the parameters (e.g., h) move from the initial MPD estimate to some other median value. Pairs plots of the estimated parameters (starting at Figure E.26) show no undesirable correlations between parameters. In particular, steepness h and the natural mortality parameters (M_1,M_2) show little correlation, suggesting that sufficient data exist to estimate these parameters simultaneously. Trace plots of the derived quantities 'female spawning biomass' (Figure E.32) and recruitment (Figure E.33) also show good convergence properties. Thus, the MCMC computations seem satisfactory.

Marginal posterior distributions and corresponding priors for the estimated parameters are shown in Figure E.34. For some of the parameters (e.g., M_2), the model finds enough information to move the posterior distribution away from the prior. The estimate of female natural mortality, M_1, shifted slightly higher from 0.06 to 0.062 while male natural mortality, M_2, shifted noticeably lower from 0.06 to 0.051. The h posterior basically mirrored the prior. Corresponding summary statistics for the estimated parameters are given in Table E.2.

The marginal posterior distribution of vulnerable biomass and catch (Figure E.35) shows a decline in the population from 1965 to aprroximately 1992, and a levelling off since then. The median spawning biomass relative to unfished equilibrium values (Figure E.36) reached a minimum of 0.513 in 1991 and currently sits at 0.559. The recruitment patterns for Silvergray Rockfish show occasional upticks in 1982, 1991, and 2000 (Figure E.37). Exploitation rates were elevated during various periods around 1965, 1988, 1994, and peaked in 1988 at a median value of 0.103 (Figure E.38). A phase plot showing the time-evolution of spawning biomass and exploitation rate relative to B_{MSY} and u_{MSY} (Figure E.39) show a meandering within a good zone (low exploitation, high biomass).

E.4 PROJECTION RESULTS AND DECISION TABLES

Projections were made to evaluate the future behaviour of the population under different levels of constant catch, given the model assumptions. The projections, starting with the biomass at the beginning of 2014, were made over a range of constant catch strategies (0-3,000 t) for each of the 1,000 MCMC samples in the posterior, generating future biomass trends by assuming random recruitment deviations. Future recruitments were generated through the stock-recruitment function using recruitment deviations drawn randomly from a lognormal distribution with zero mean and constant standard deviation (see Appendix D for full details). Projections were made for 10 years. This time frame was considered to be long enough to satisify the 'long-term' requirement of the Request for Science Information and Advice, yet short enough for the projected recruitments to be mainly based on individuals spawned before 2014 (and hence already estimated by the model).

Resulting projections of spawning biomass are shown for selected catch strategies (Figure E.40). These suggest that the recent increase in spawning biomass would most likely continue for a catch of 1500 t, which is larger than the recent average catch of 1431 t.

Note that recruitment is drawn from the estimated stock-recruitment curve with lognormal error that has a standard deviation of 0.6 and a mean of zero. However, this approach of average recruitment does not accurately simulate the occasional large recruitment events that have occurred for this stock (Figure E.37).

Decision tables give the probabilities of the spawning biomass exceeding the reference points in specified years, calculated by counting the proportion of MCMC samples for which the biomass exceeded the given reference point.

Results for the three B_{MSY}-based reference points are presented in Tables E.4-E.6. For example, the estimated probability that the stock is in the provisional healthy zone in 2017 under a constant catch strategy of 1,000 t is $\mathrm{P}(B_{2017} > 0.8B_{\mathrm{MSY}}) = 1$ (row '1000' and column '2017' in Table E.5).

Table E.7 provides probabilities that projected spawning biomass B_t will exceed the current-year biomass B_{2014} at the various catch levels. The first column populated by zero values simply means that the current-year biomass will never be greater than itself. Table E.8 shows the

probabilities of projected exploitation rate u_t exceeding that at MSY (u_{MSY}).

For the maximum sustainable yield (MSY) calculations, projections were run for 301 values of constant exploitation rate u_t between 0.001 and 0.301, until an equilibrium yield was reached within a tolerance of 0.01 t (or until 15,000 years had been reached). This was done for each of the 1,000 samples. The lower bound of u_t was reached for none of the MCMC samples, and the upper bound was reached by 78 of the samples. Of the 301,000 projection calculations, all converged by 15,000 years.

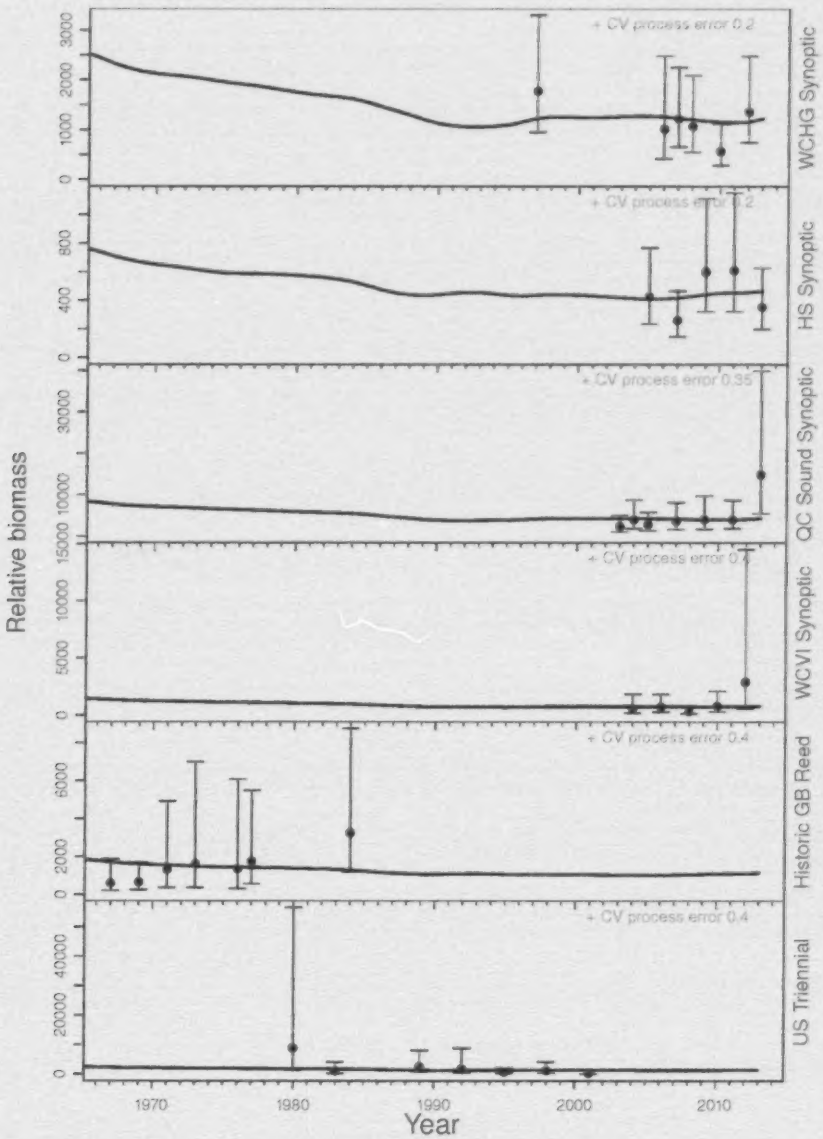

Figure E.1. Survey index values (points) with 95% confidence intervals (bars) and MPD model fits (curves) for the fishery-independent survey series.

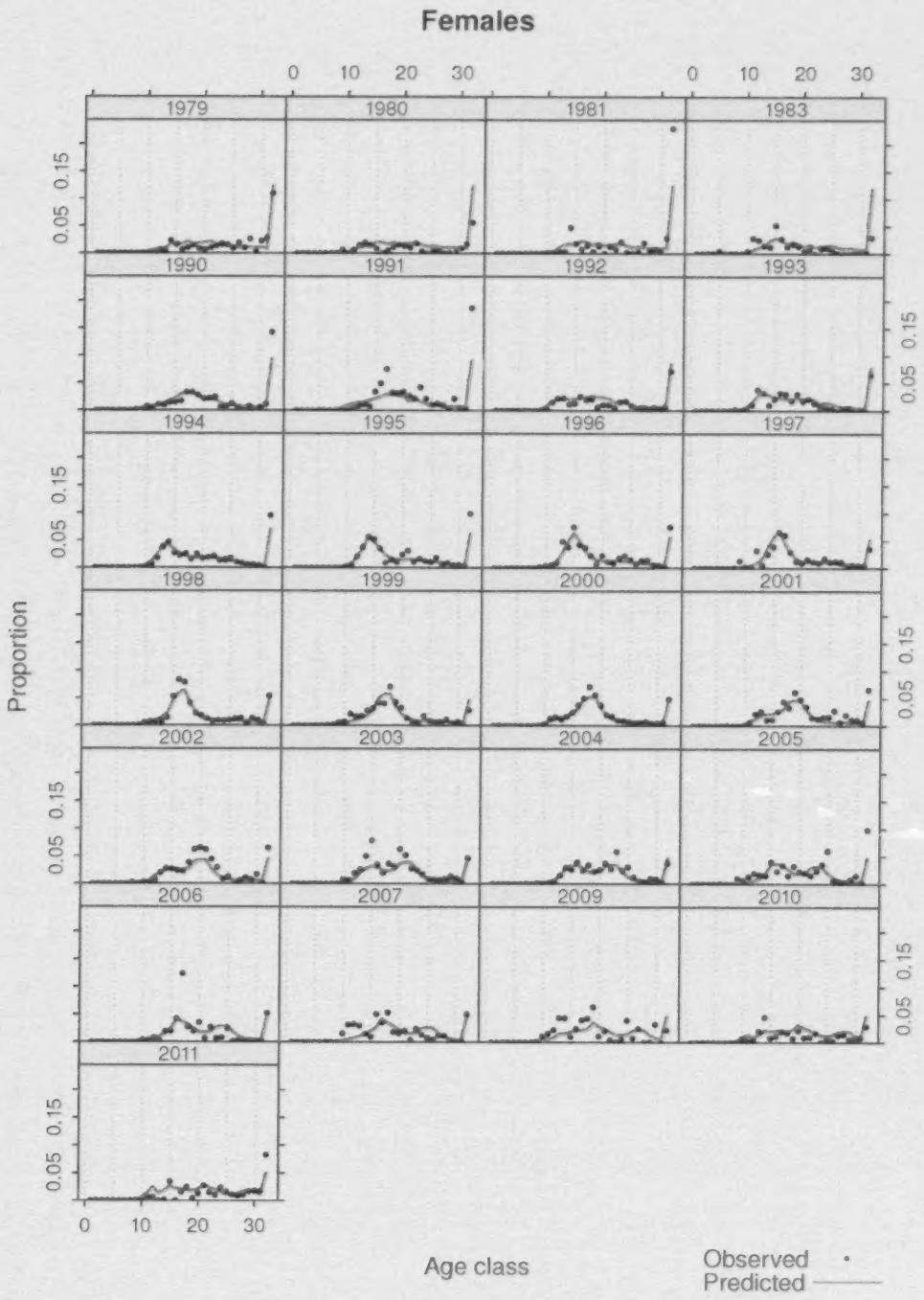

Figure E.2. Observed and predicted commercial proportions-at-age for females. Note that years are not consecutive.

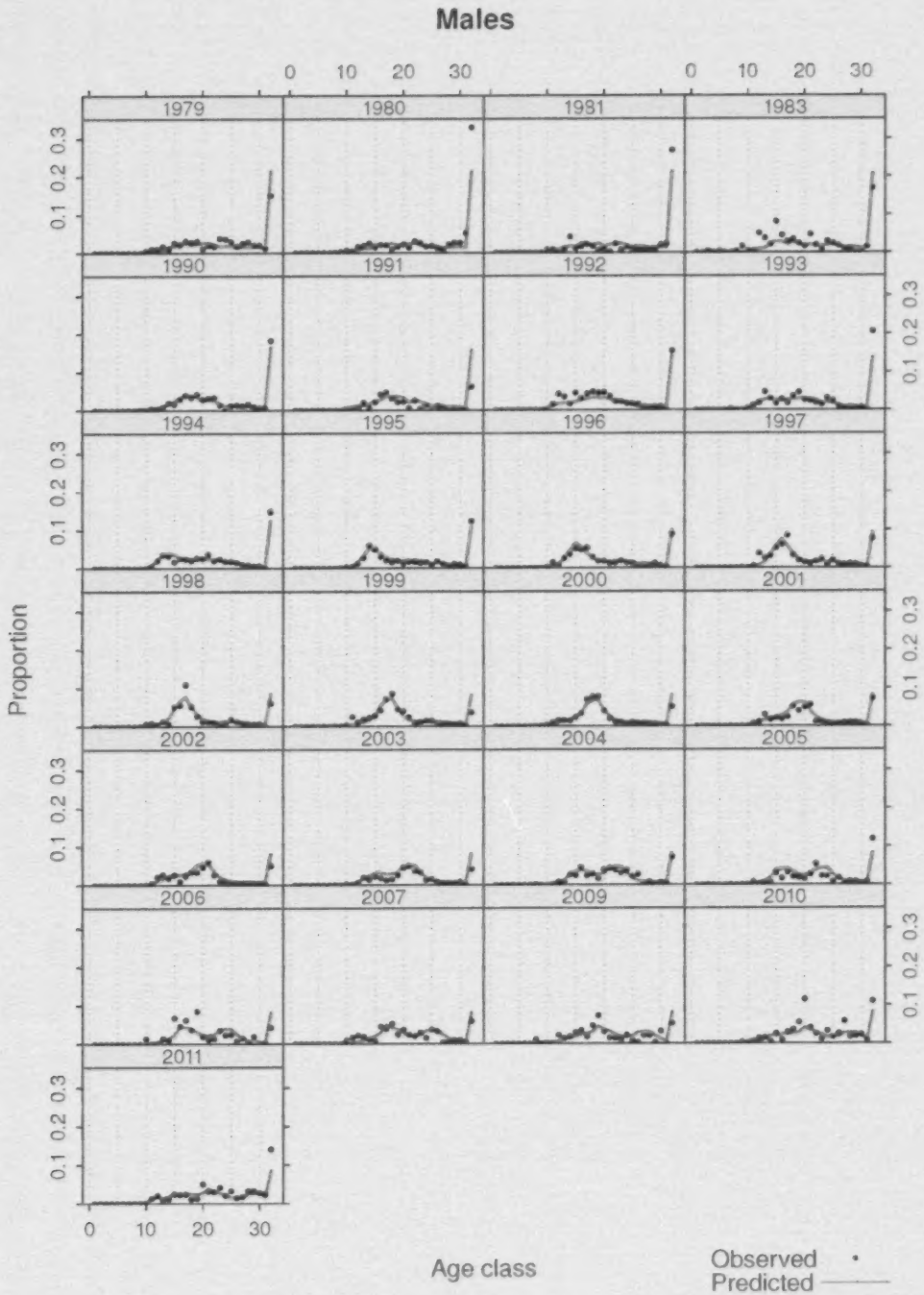

Figure E.3. Observed and predicted commercial proportions-at-age for males. Note that years are not consecutive.

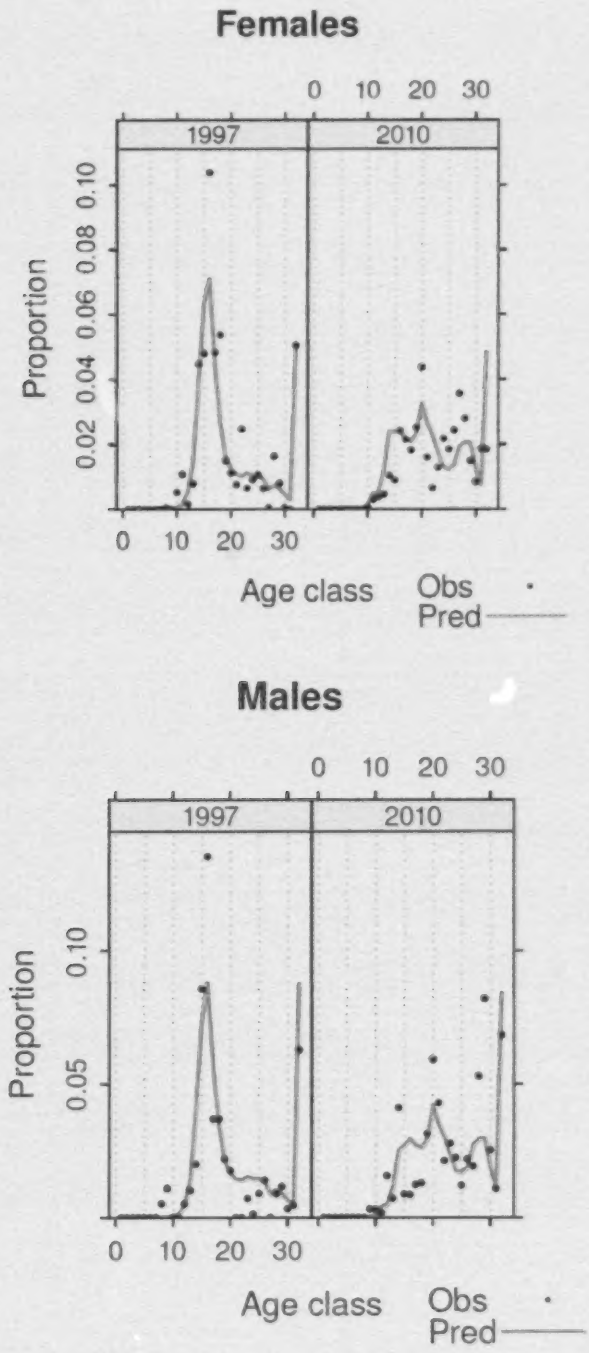

Figure E.4. Observed and predicted proportions-at-age for WCHG synoptic survey.

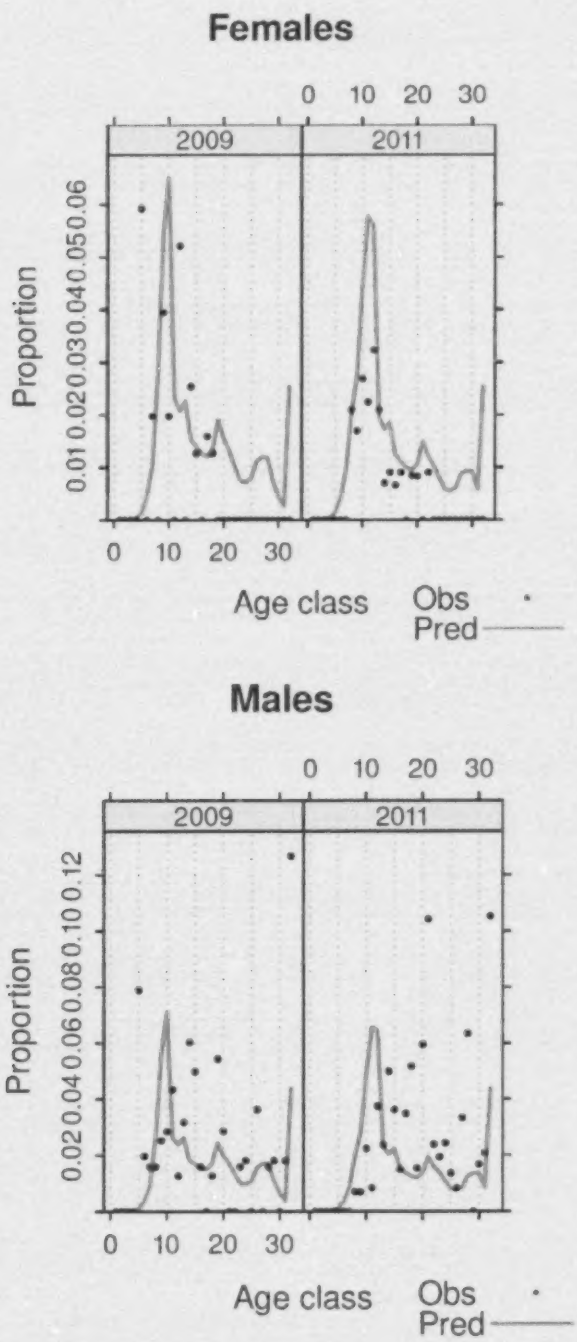

Figure E.5. Observed and predicted proportions-at-age for HS synoptic survey.

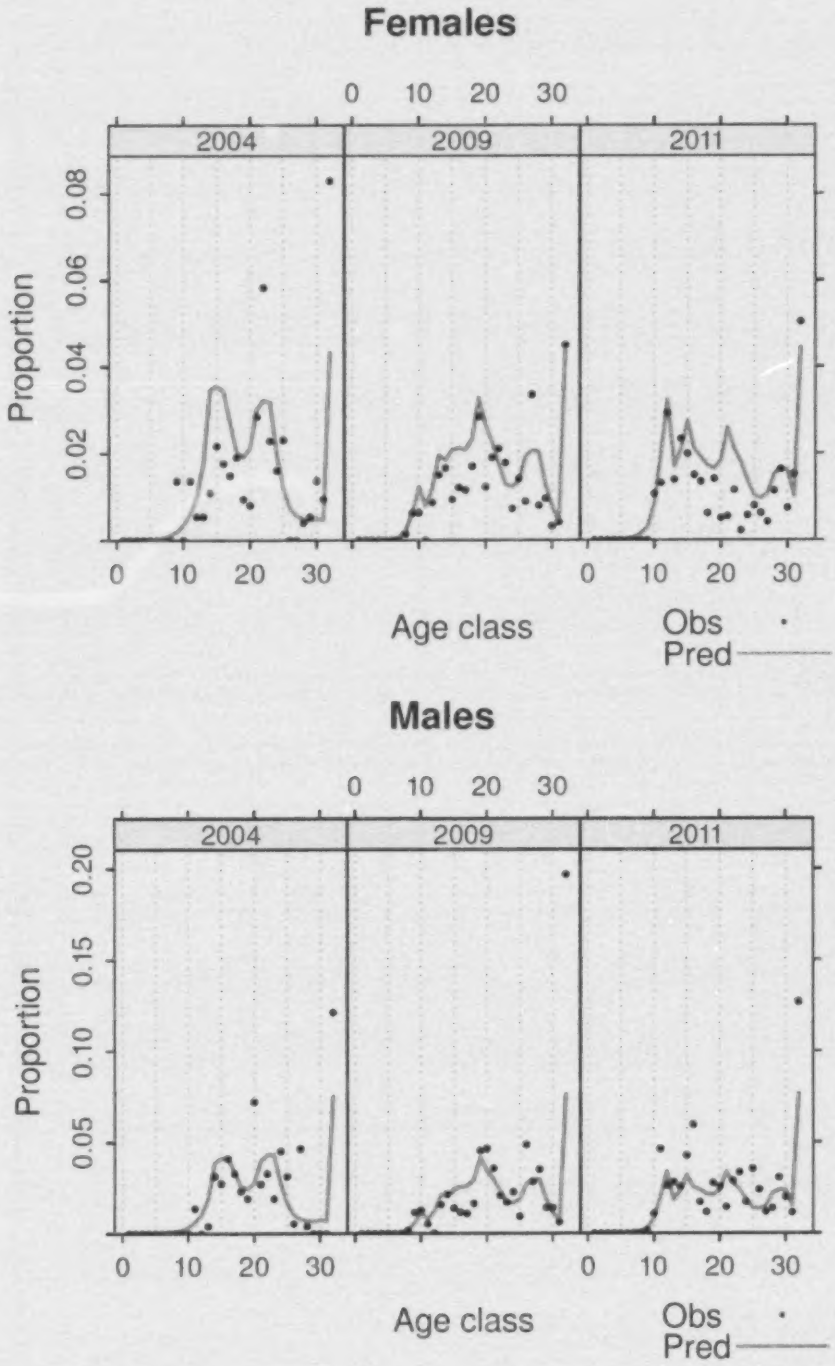

Figure E.6. Observed and predicted proportions-at-age for QCSound synoptic survey.

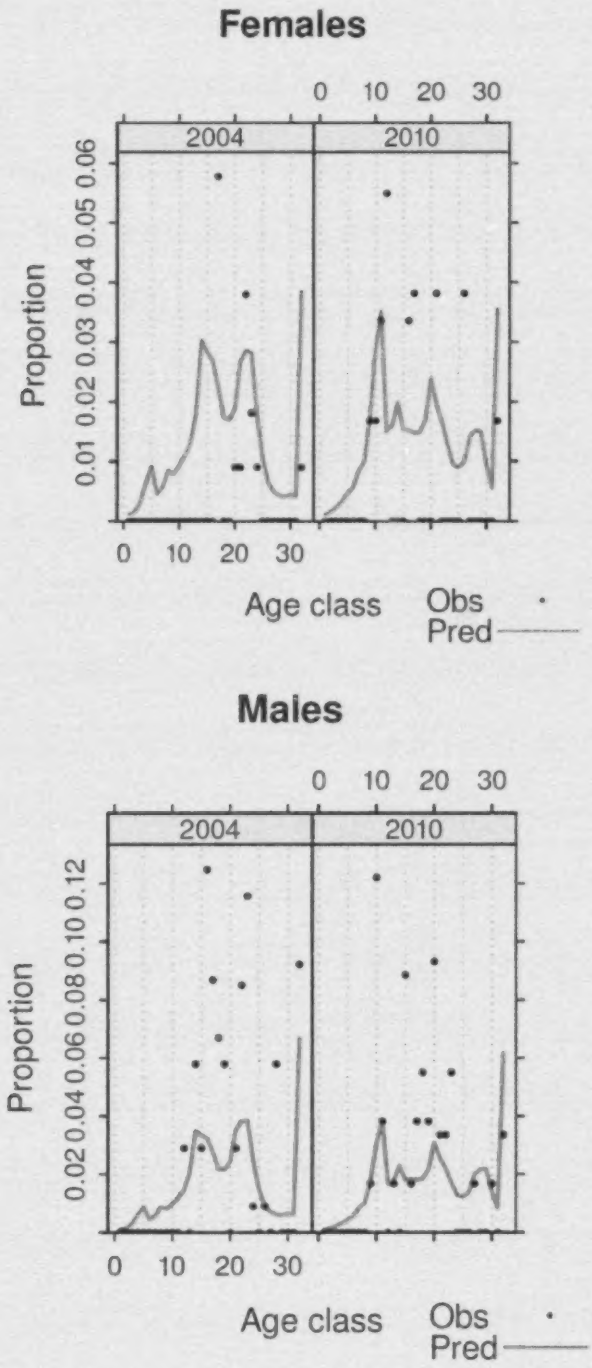

Figure E.7. Observed and predicted proportions-at-age for WCVI synoptic survey.

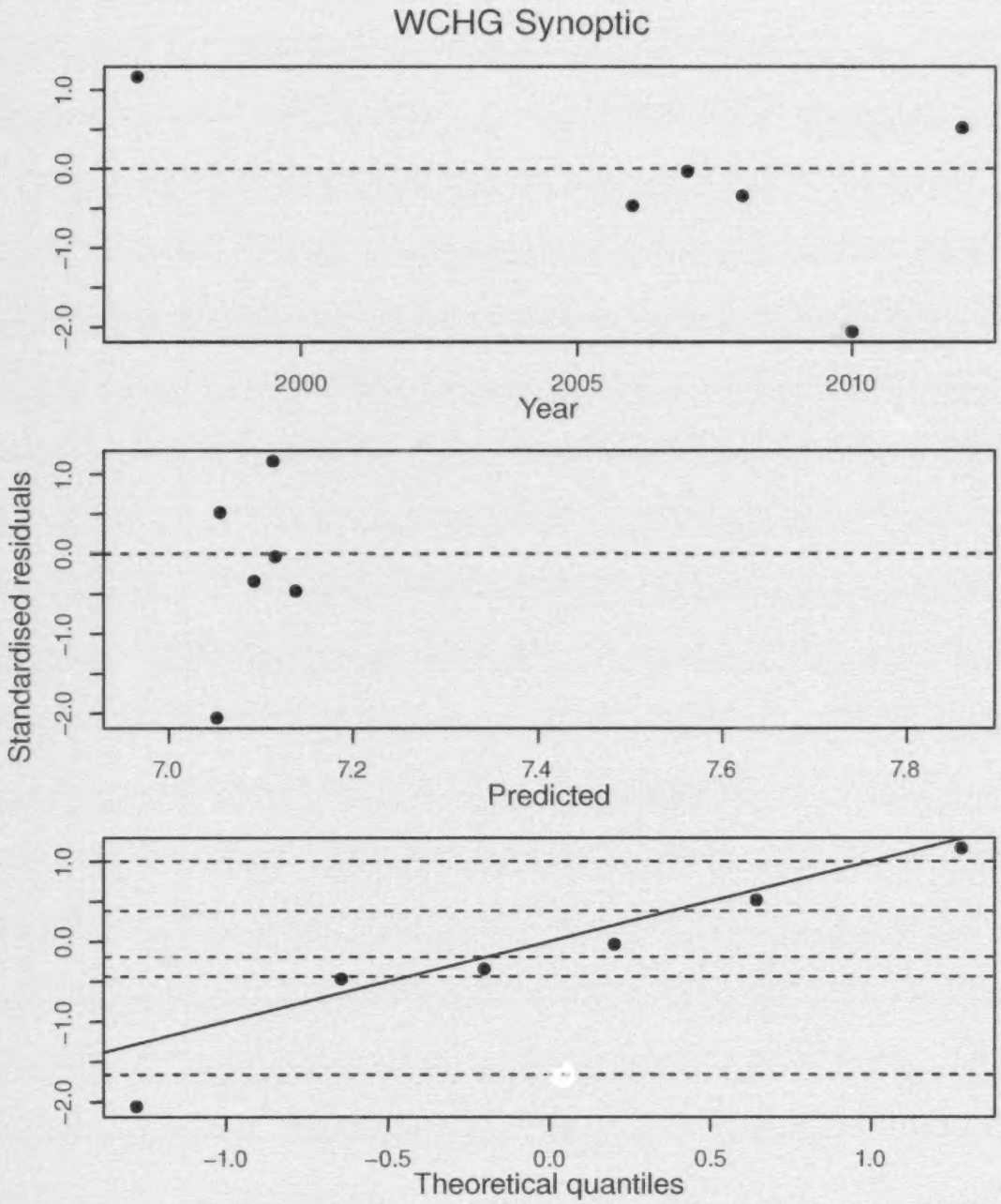

Figure E.8. Residuals of fits of model to WCHG synoptic survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

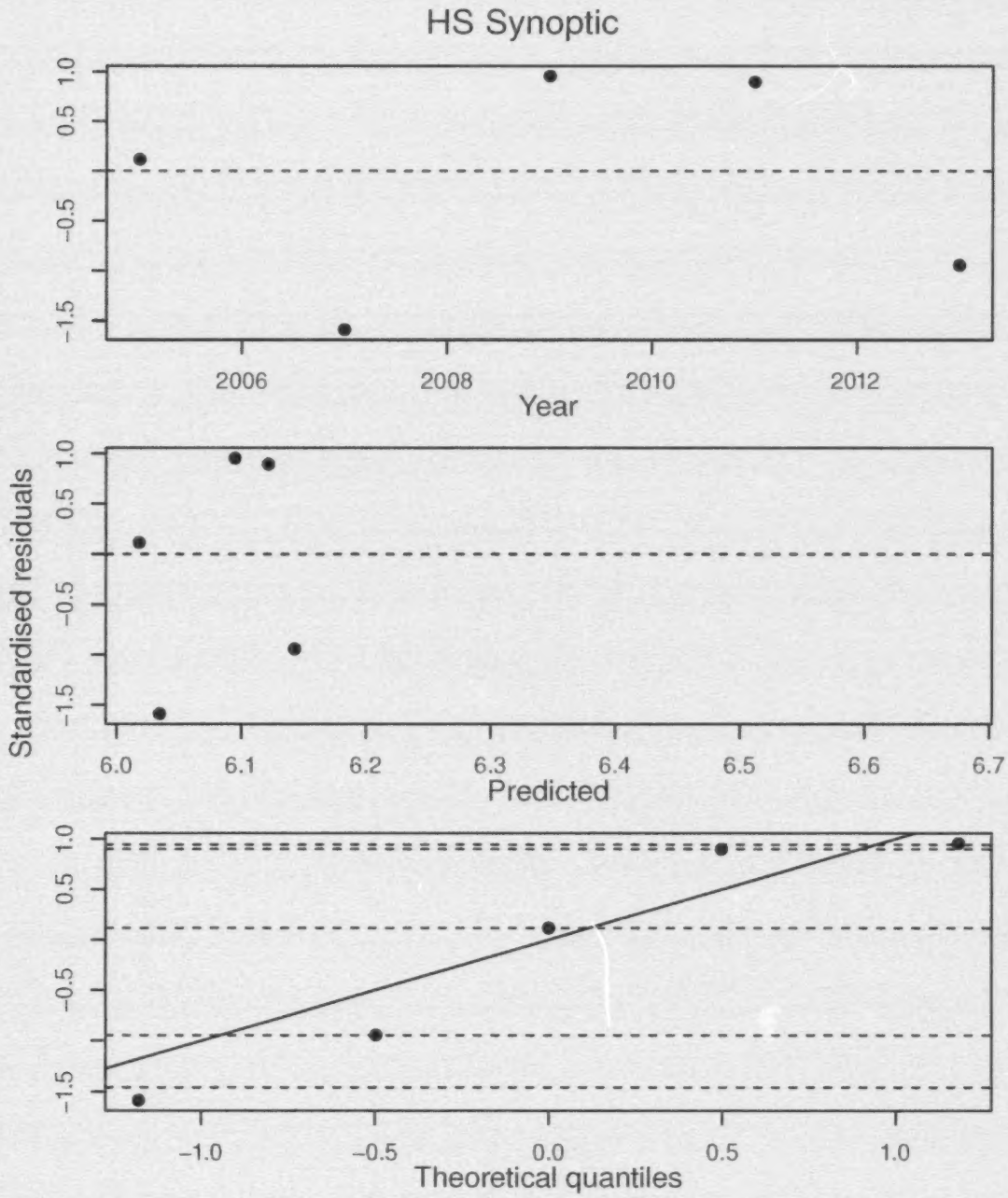

Figure E.9. Residuals of fits of model to HS synoptic survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

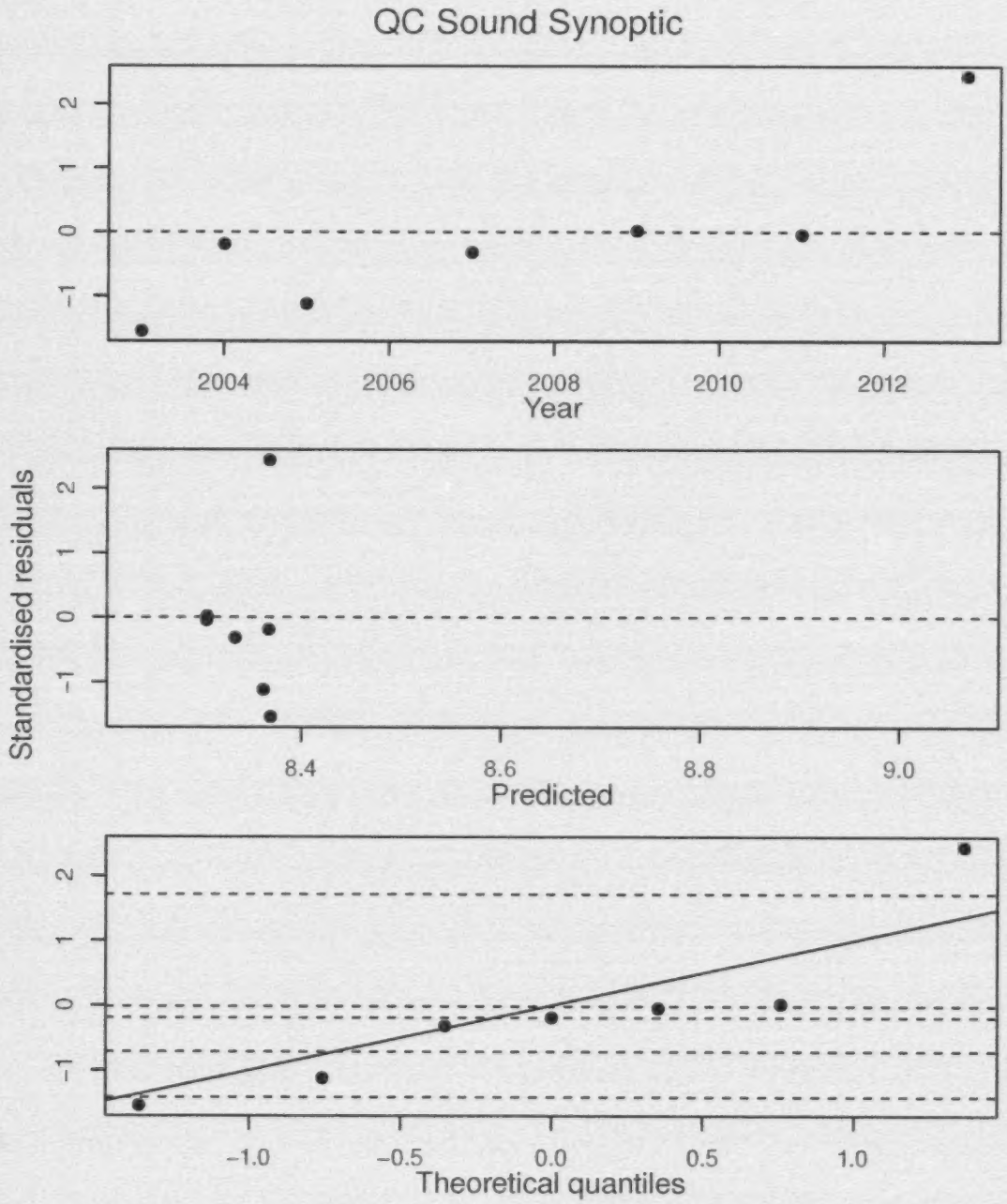

Figure E.10. Residuals of fits of model to QCS synoptic survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

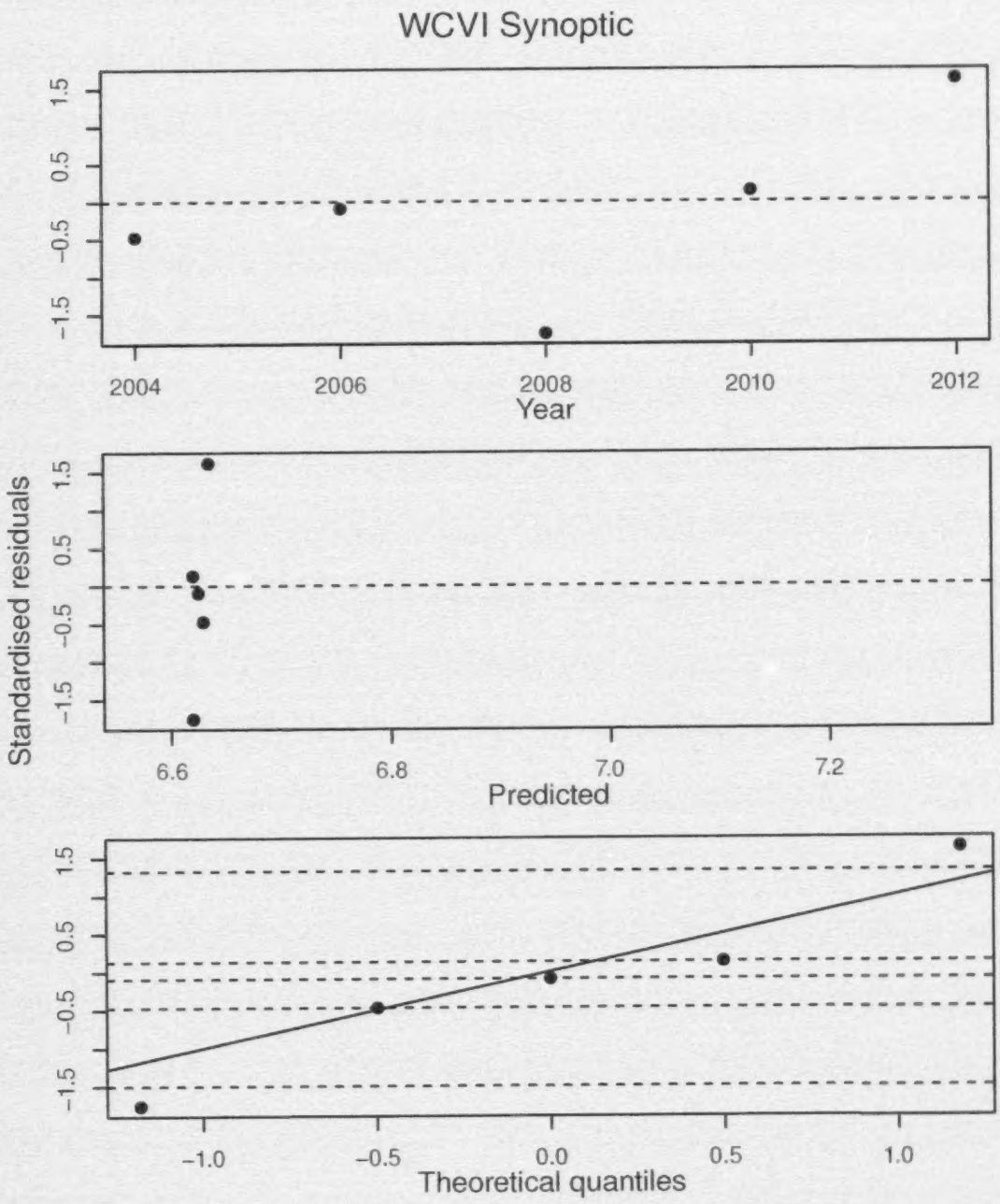

Figure E.11. Residuals of fits of model to WCVI synoptic survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

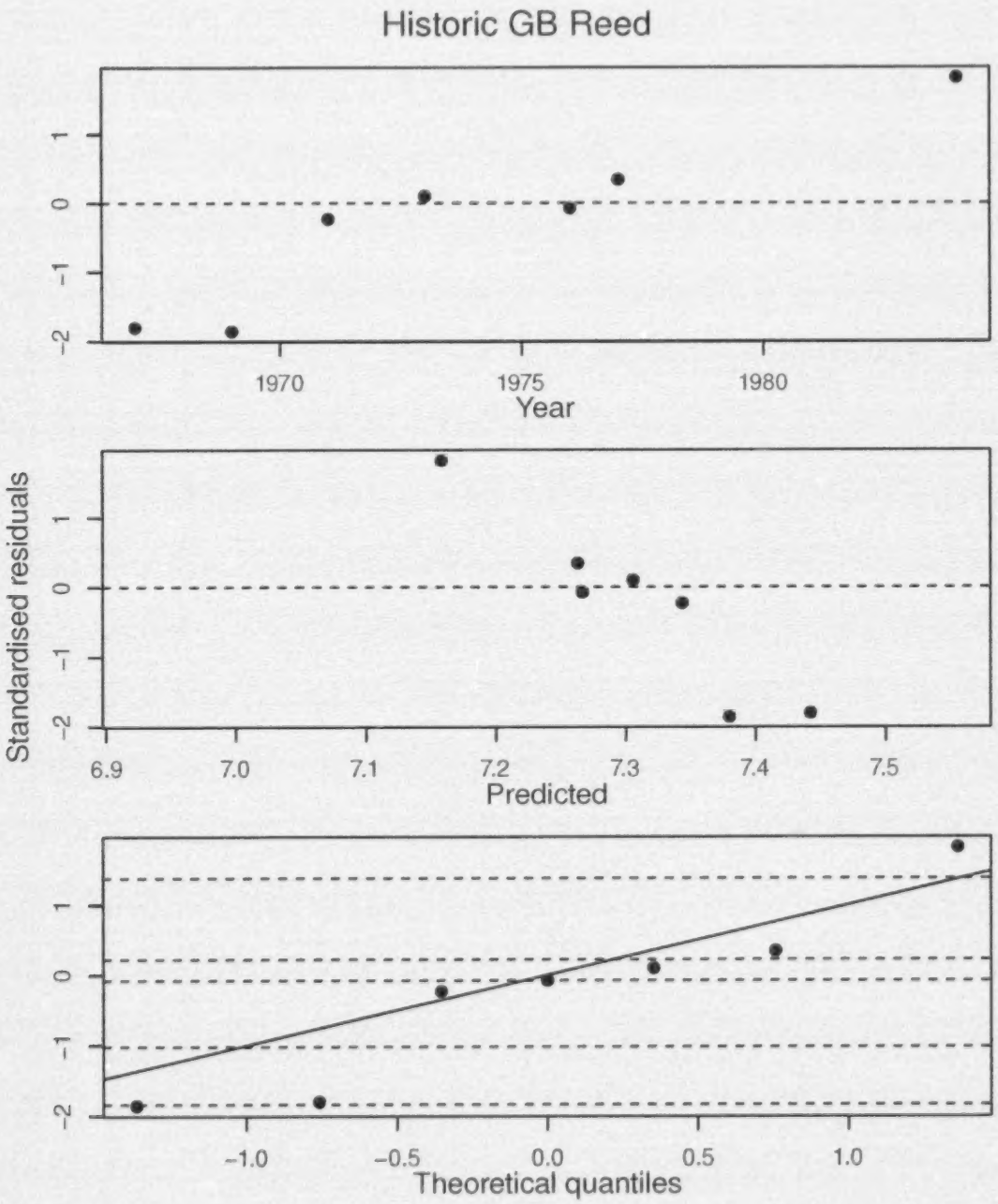

Figure E.12. Residuals of fits of model to Historic GB Reed survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

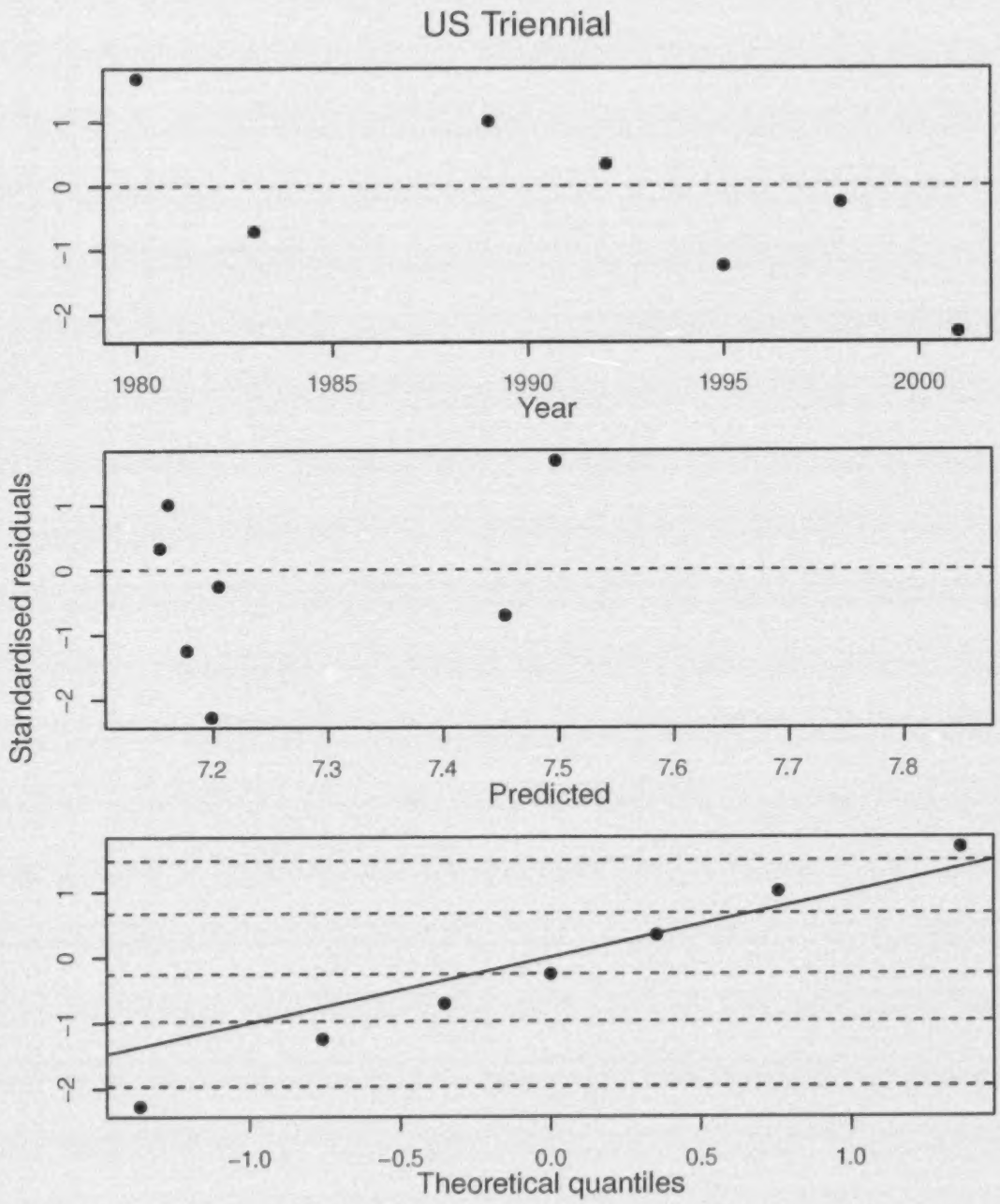

Figure E.13. Residuals of fits of model to US Triennial survey series (MPD values). Vertical axes are standardised residuals. The three plots show, respectively, residuals by year of index, residuals relative to predicted index, and normal quantile-quantile plot for residuals (horizontal lines give 5, 25, 50, 75 and 95 percentiles).

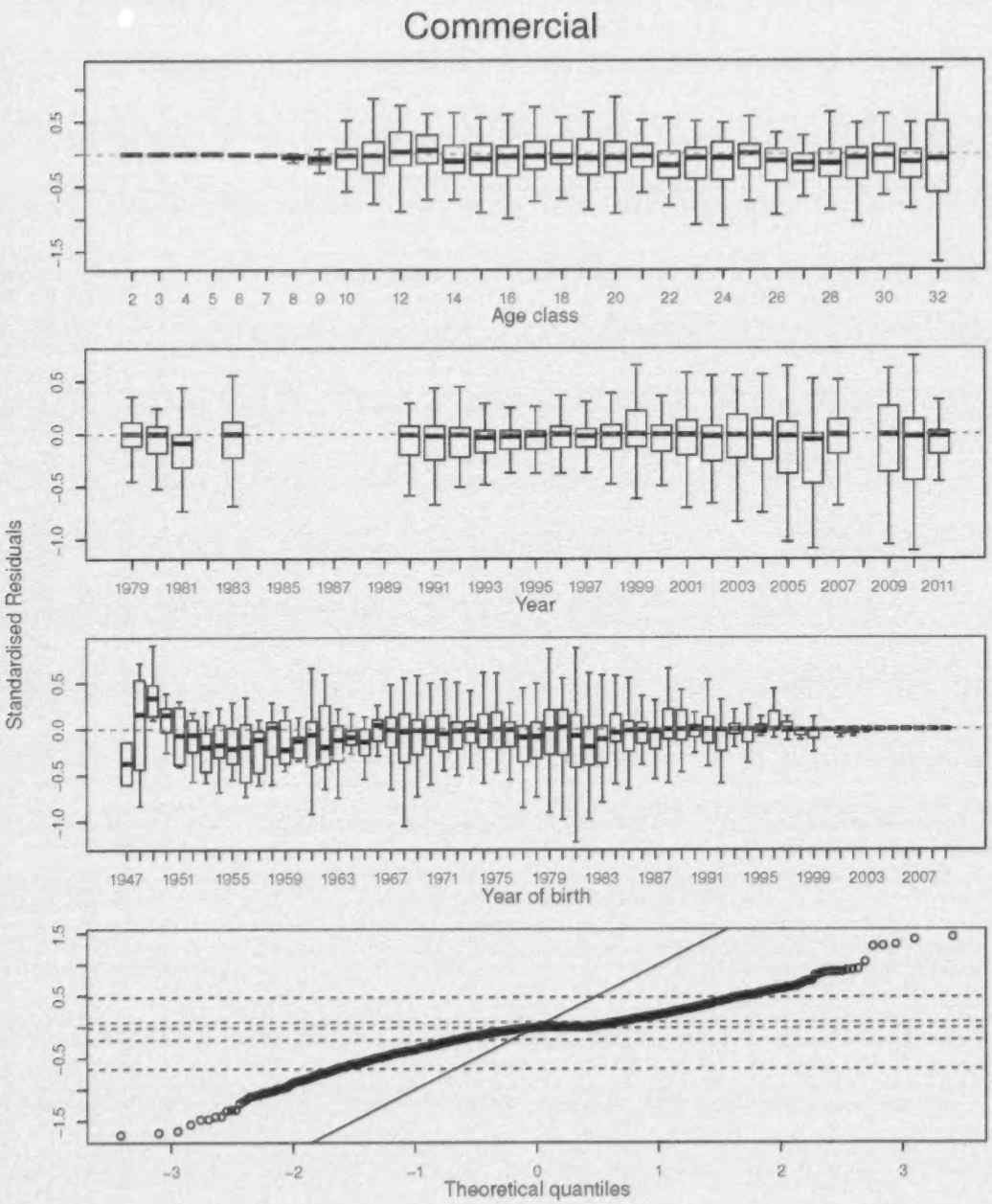

Figure E.14. Residual of fits of model to commercial proportions-at-age data (MPD values). Vertical axes are standardised residuals. Boxplots show, respectively, residuals by age class, by year of data, and by year of birth (following a cohort through time). Boxes give interquartile ranges, with bold lines representing medians and whiskers extending to the most extreme data point that is < 1.5 times the interquartile range from the box. Bottom panel is the normal quantile-quantile plot for residuals, with the 1:1 line, though residuals are not expected to be normally distributed because of the likelihood function used; horizontal lines give the 5, 25, 50, 75, and 95 percentiles (for the total of 1550 residuals).

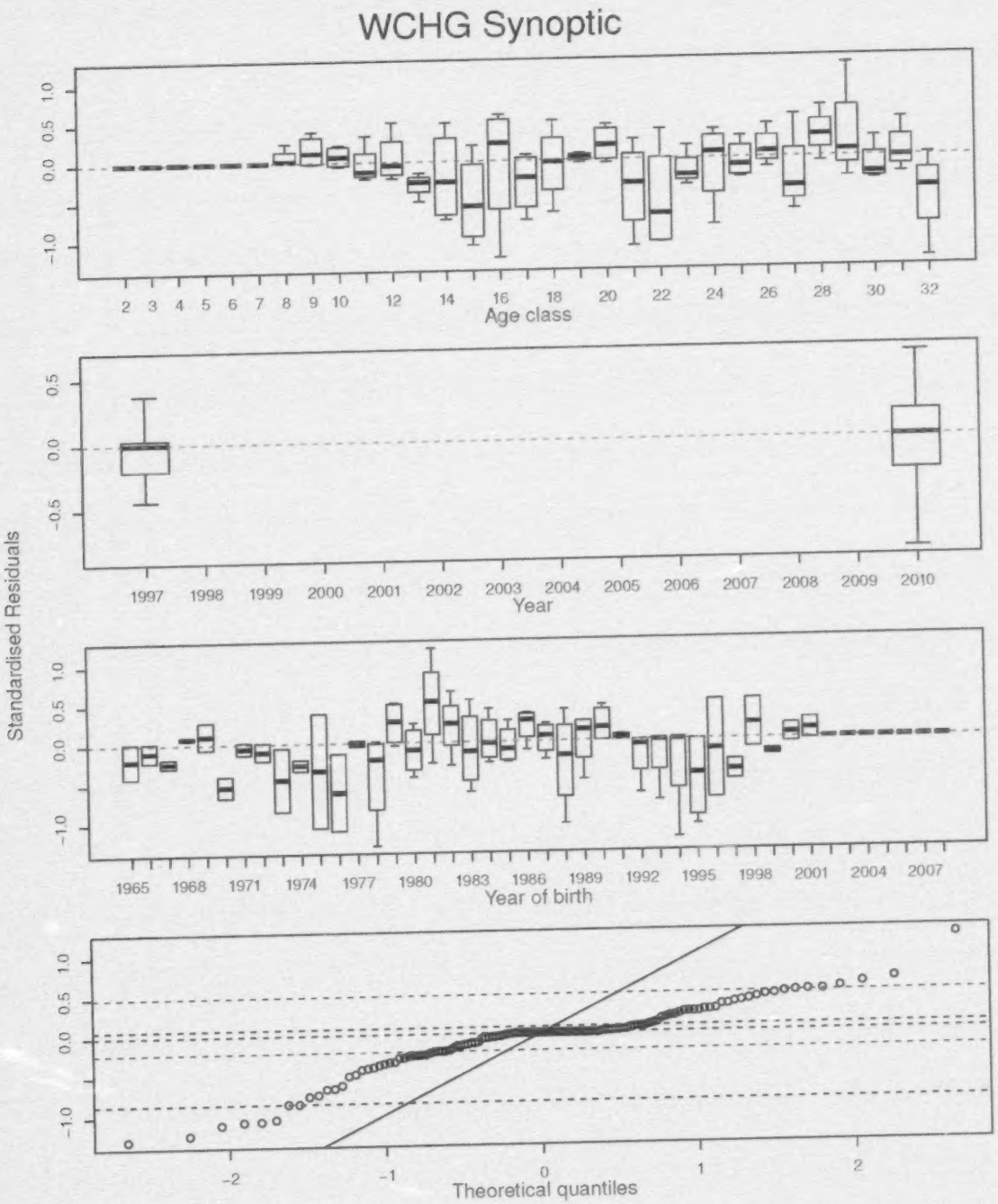

Figure E.15. Residuals of fits of model to proportions-at-age data (MPD values) from WCHG synoptic survey series. Details as for Figure E.14, for a total of 124 residuals.

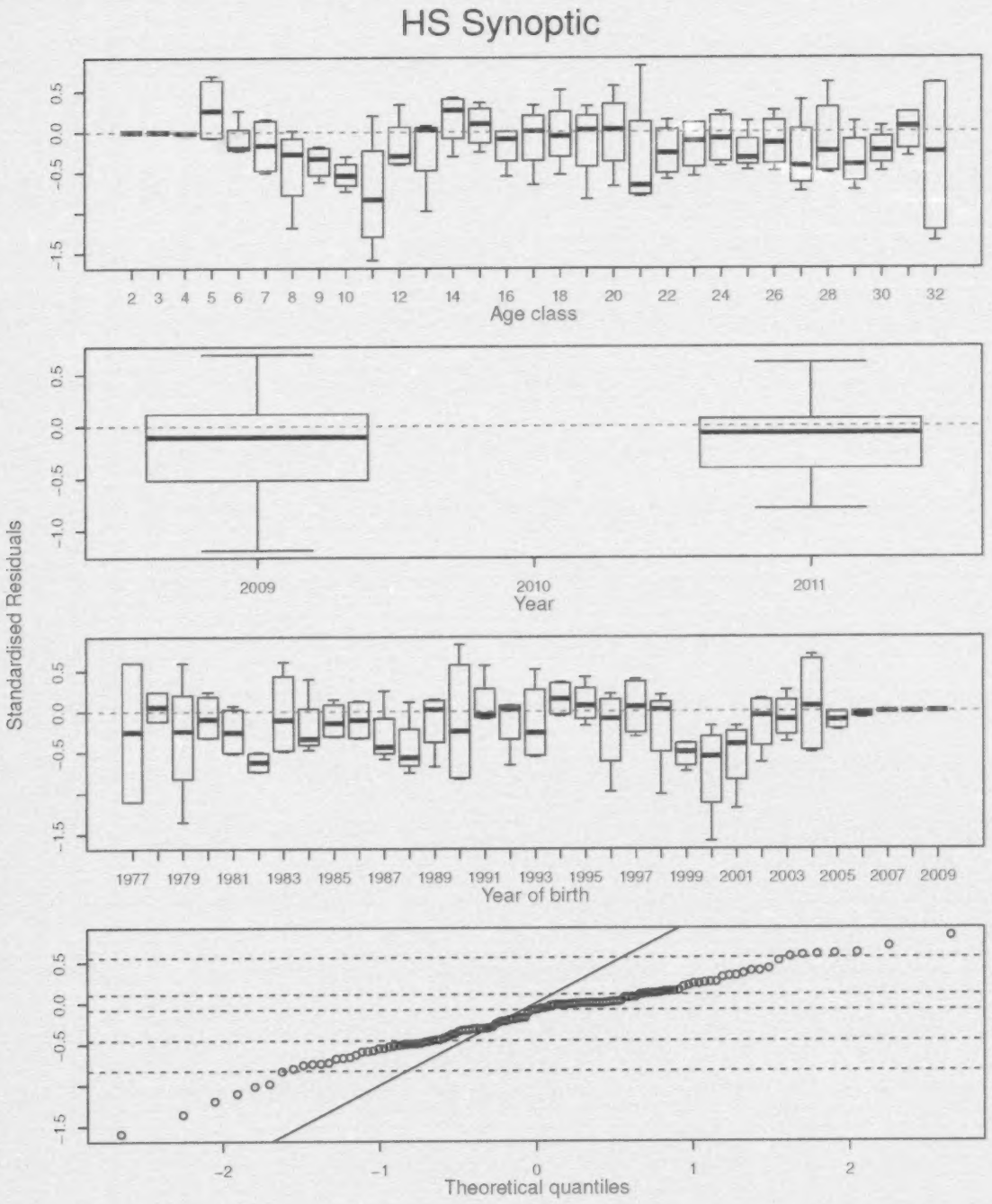

Figure E.16. Residuals of fits of model to proportions-at-age data (MPD values) from HS synoptic survey series. Details as for Figure E.14, for a total of 124 residuals.

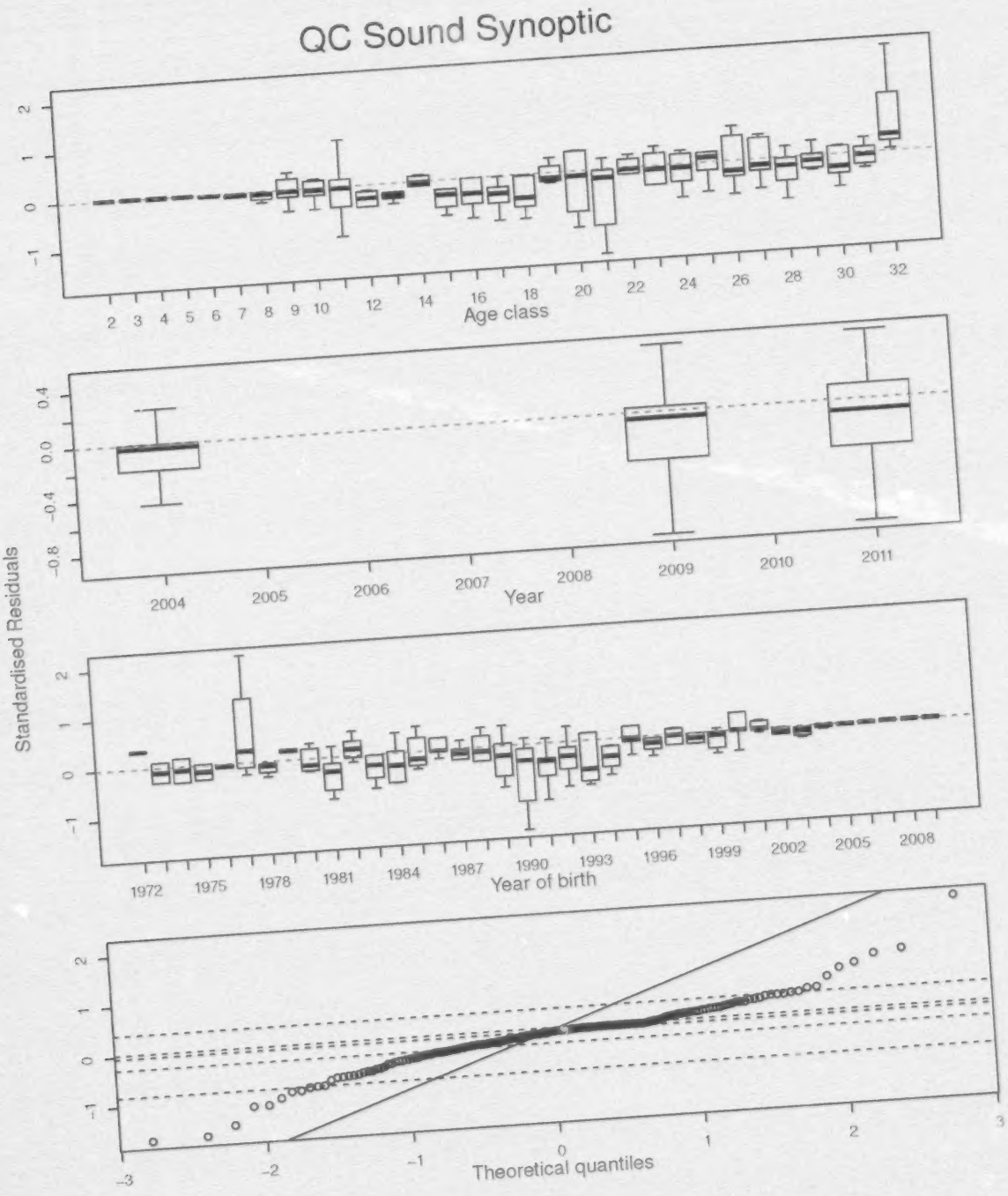

Figure E.17. Residuals of fits of model to proportions-at-age data (MPD values) from QCS synoptic survey series. Details as for Figure E.14, for a total of 186 residuals.

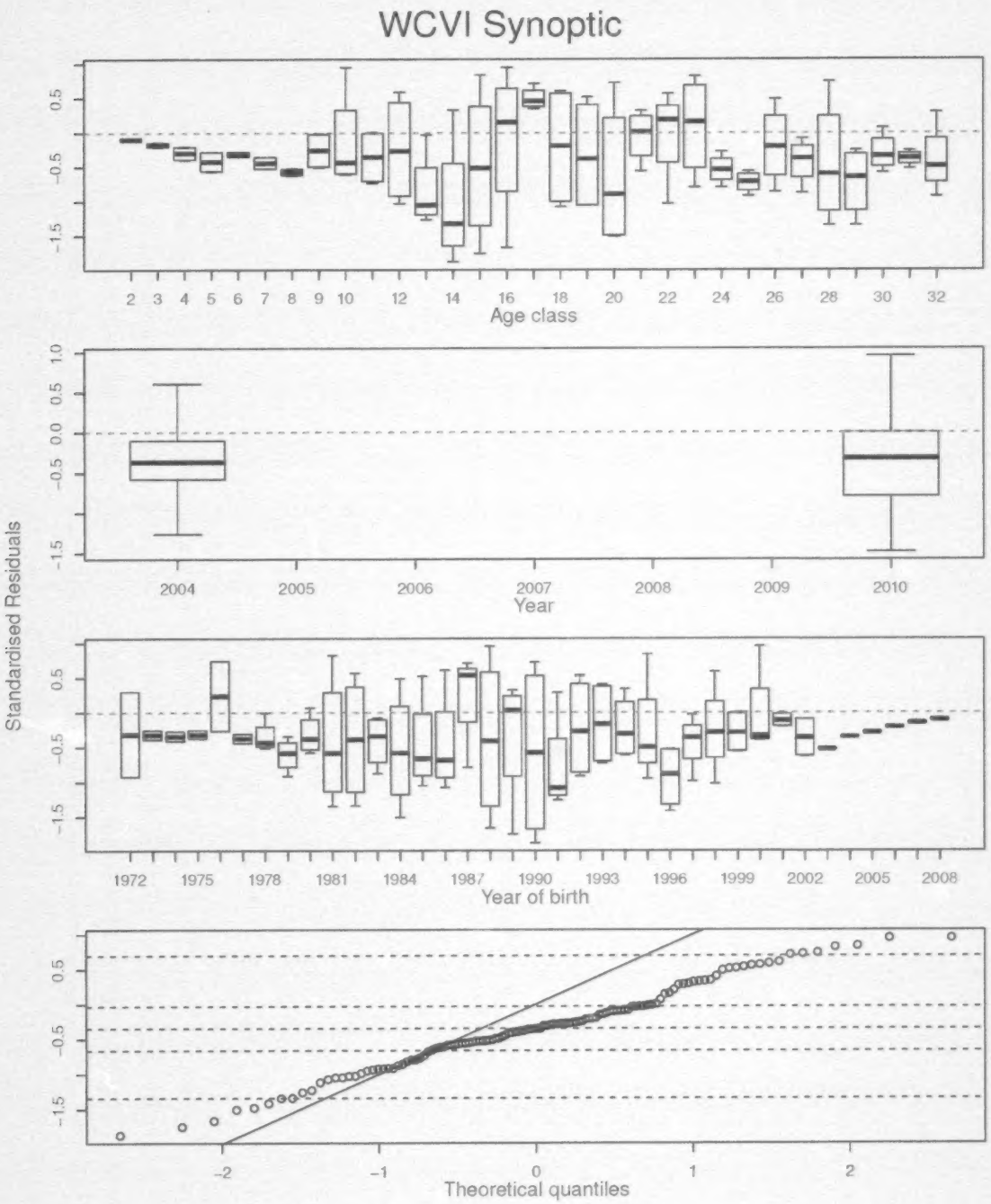

Figure E.18. Residuals of fits of model to proportions-at-age data (MPD values) from WCVI synoptic survey series. Details as for Figure E.14, for a total of 124 residuals.

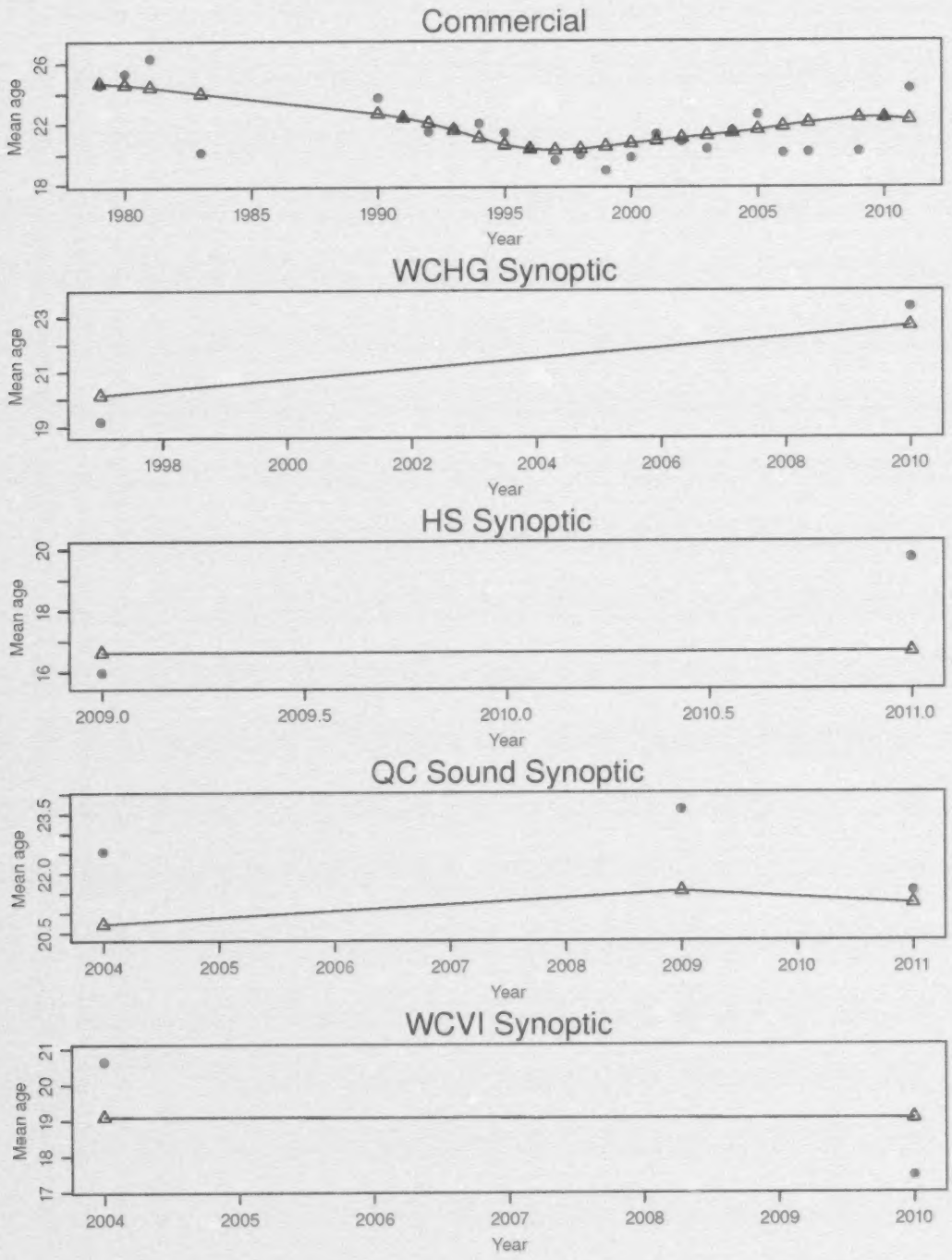

Figure E.19. Mean ages each year for the data (closed circles) and model estimates (joined open triangles) for the commercial and survey age data.

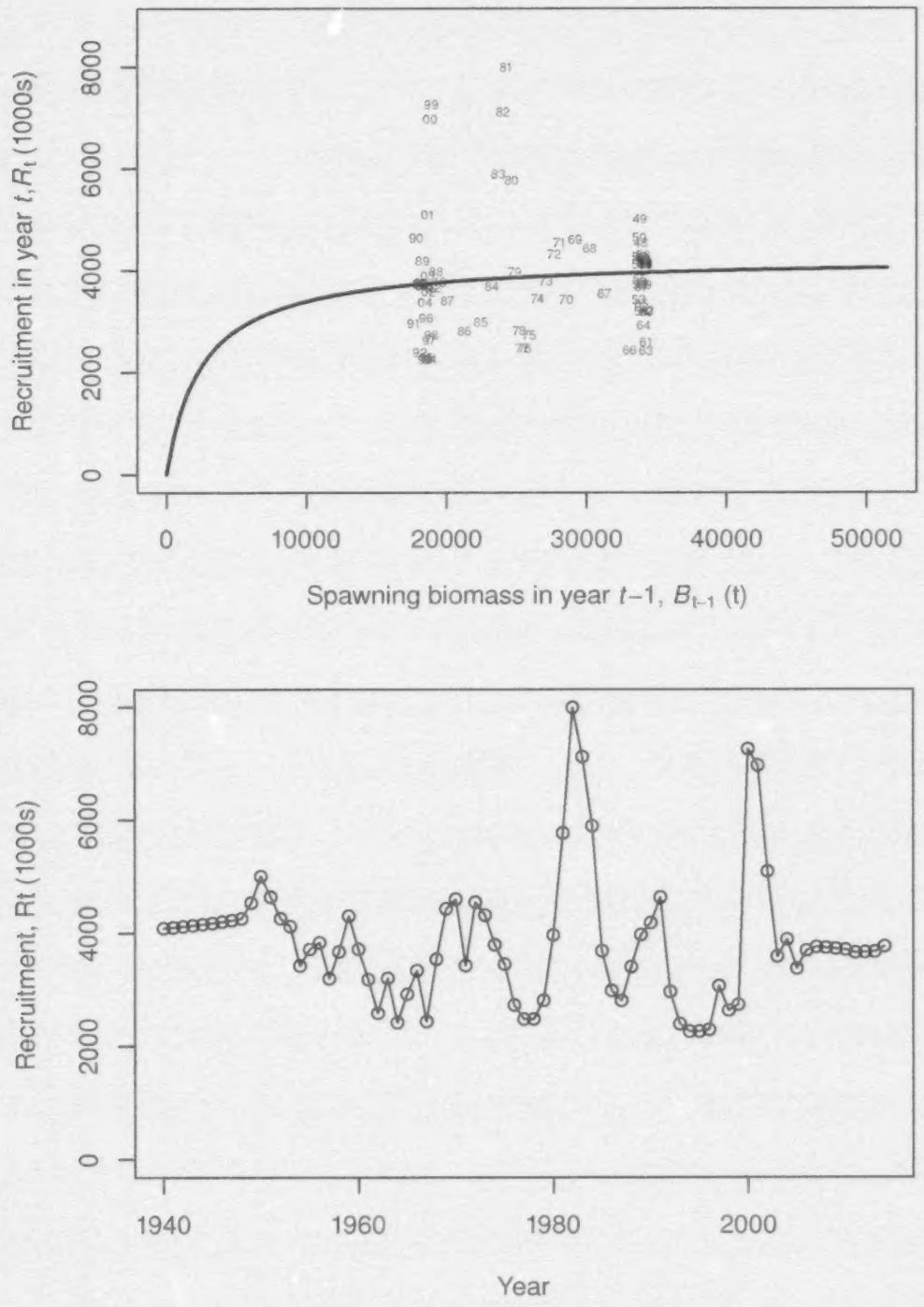

Figure E.20. Top: Deterministic stock-recruit relationship (black curve) and observed values (labelled by year of spawning) using MPD values. Bottom: Recruitment (MPD values of age-1 individuals in year t) over time, in 1,000s of age-1 individuals, with a mean of 3,851.5.

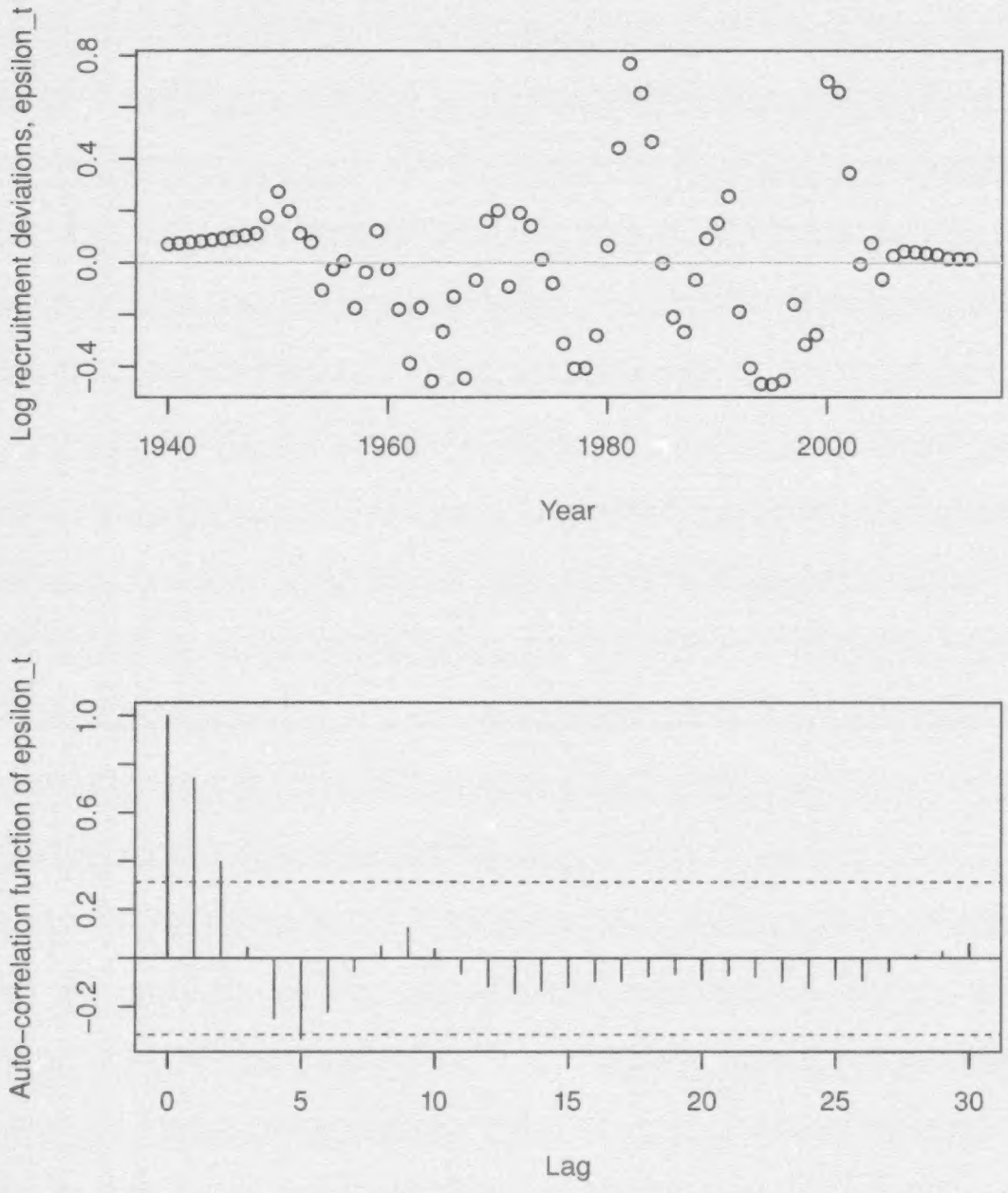

Figure E.21. Top: log of the annual recruitment deviations, ϵ_t, where bias-corrected multiplicative deviation is $e^{\epsilon_t - \sigma_R^2/2}$ where $\epsilon_t \sim$ Normal$(0, \sigma_R^2)$. Bottom: Auto-correlation function of the logged recruitment deviations (ϵ_t), for years 1961-1999 (determined as the first year of commercial age data minus the accumulator age class plus the age for which commercial selectivity for females is 0.5, to the final year that recruitments are calculated minus the age for which commercial selectivity for females is 0.5).

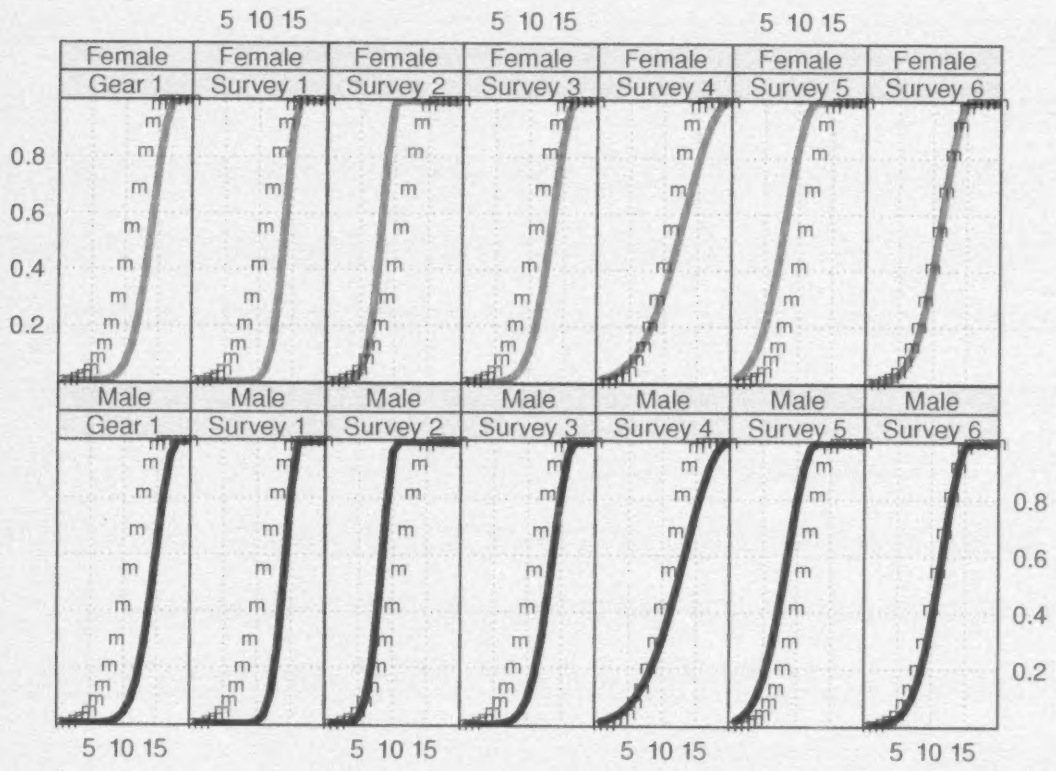

Figure E.22. Selectivities for commercial catch (labelled 'Gear 1' here) and surveys (all MPD values), with maturity ogive for females indicated by 'm'.

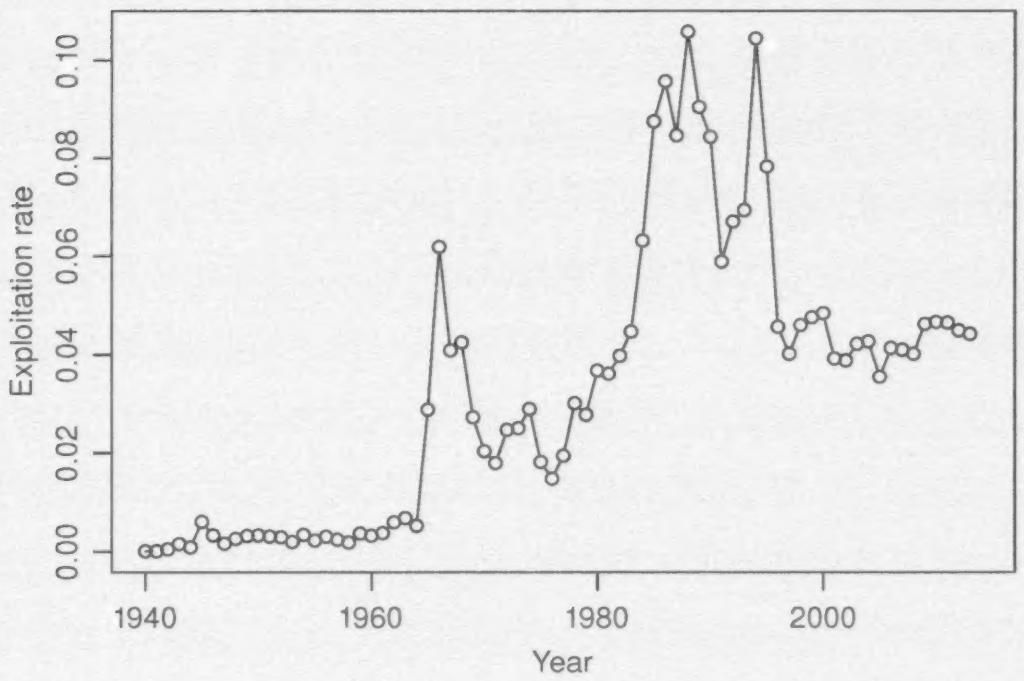

Figure E.23. Exploitation rate (MPD) over time for Silvergray Rockfish along the BC coast.

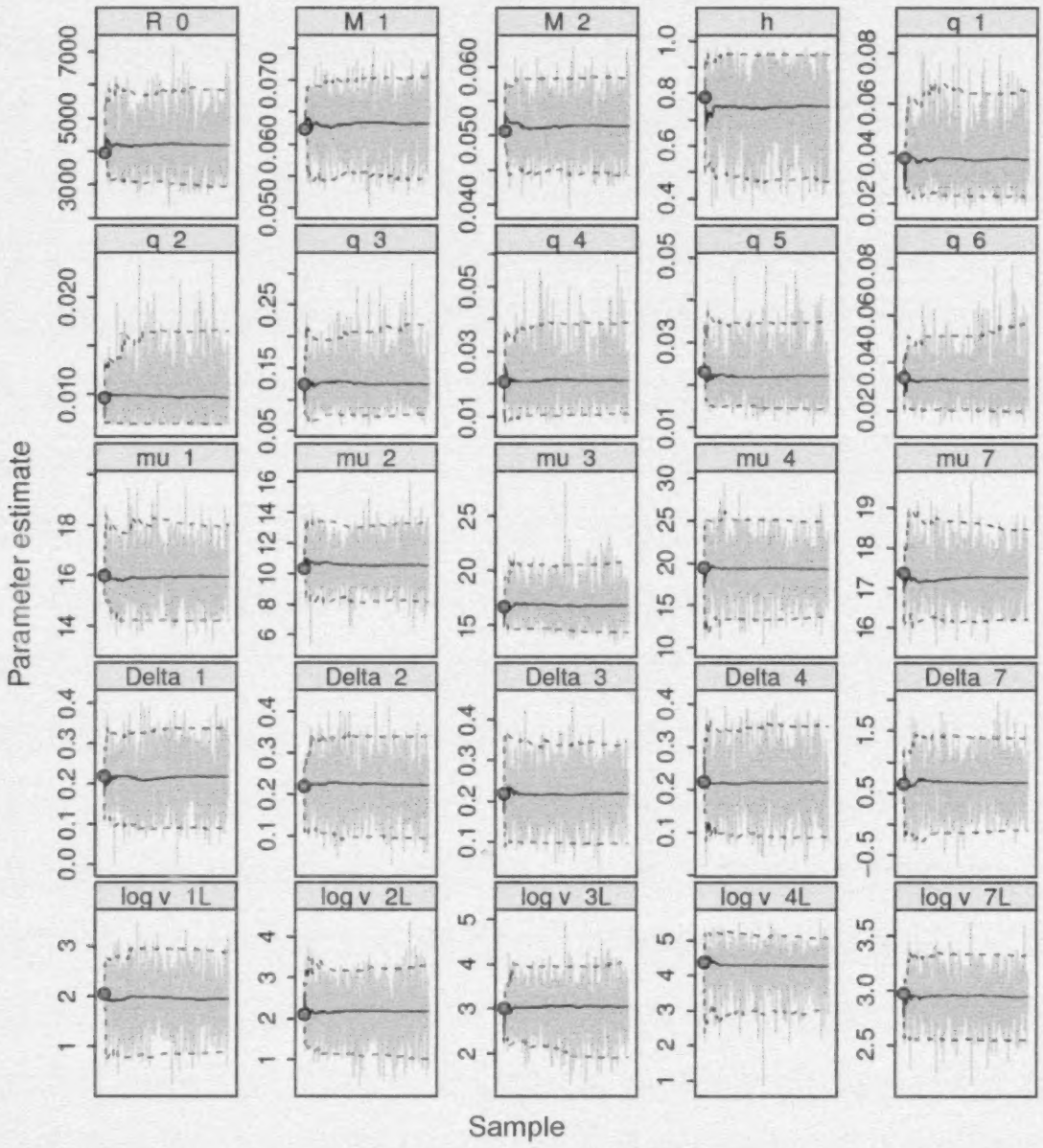

Figure E.24. MCMC traces for the estimated parameters. Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates. For parameters other than M *(if estimated), subscripts* ≤ 6 *correspond to fishery-independent surveys, and subscripts* ≥ 7 *denote the commercial fishery. Parameter notation is described in Appendix D.*

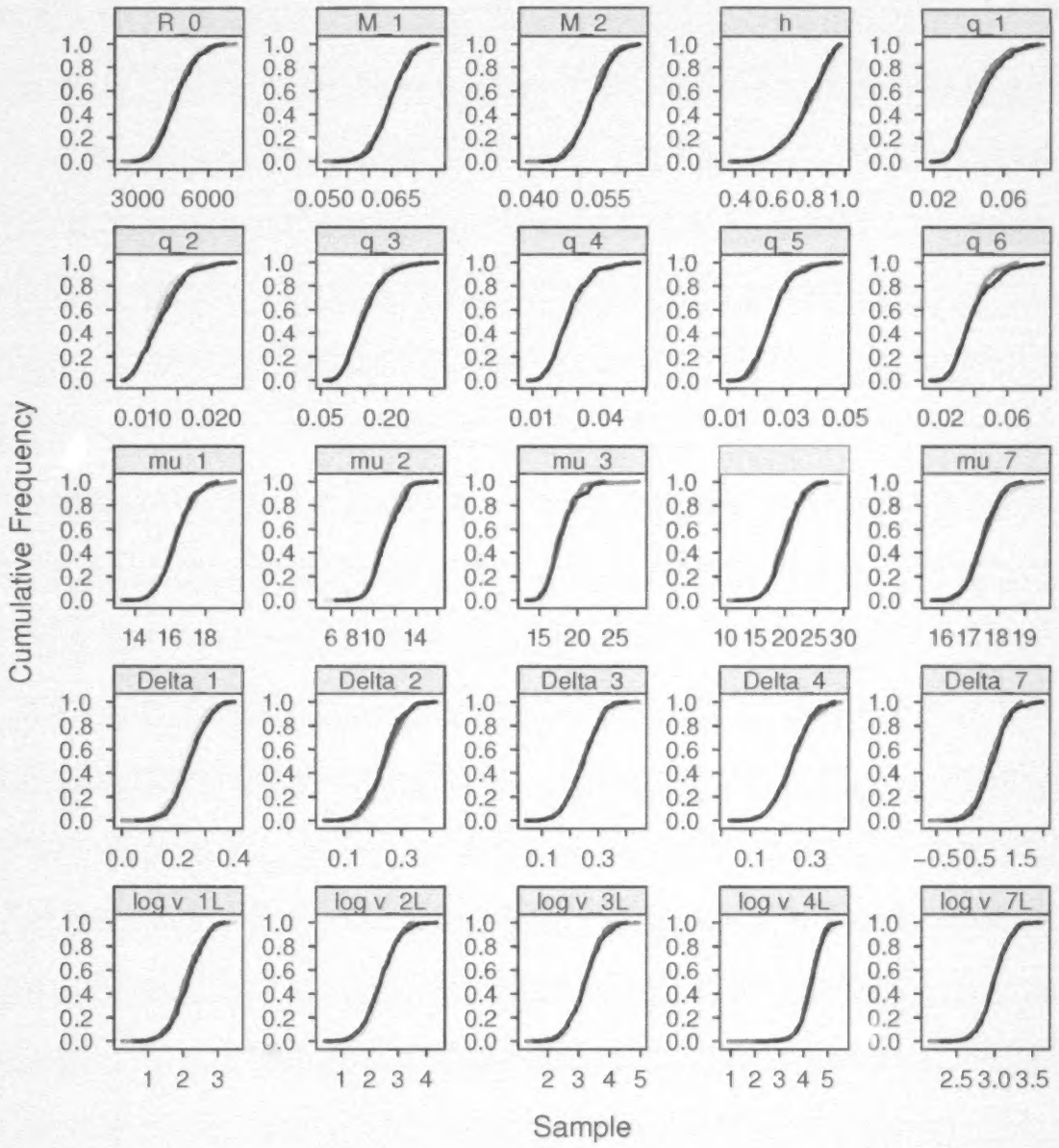

Figure E.25. Diagnostic plot obtained by dividing the MCMC chain of 1,000 MCMC samples into three segments, and overplotting the cumulative distributions of the first segment (green), second segment (red) and final segment (blue).

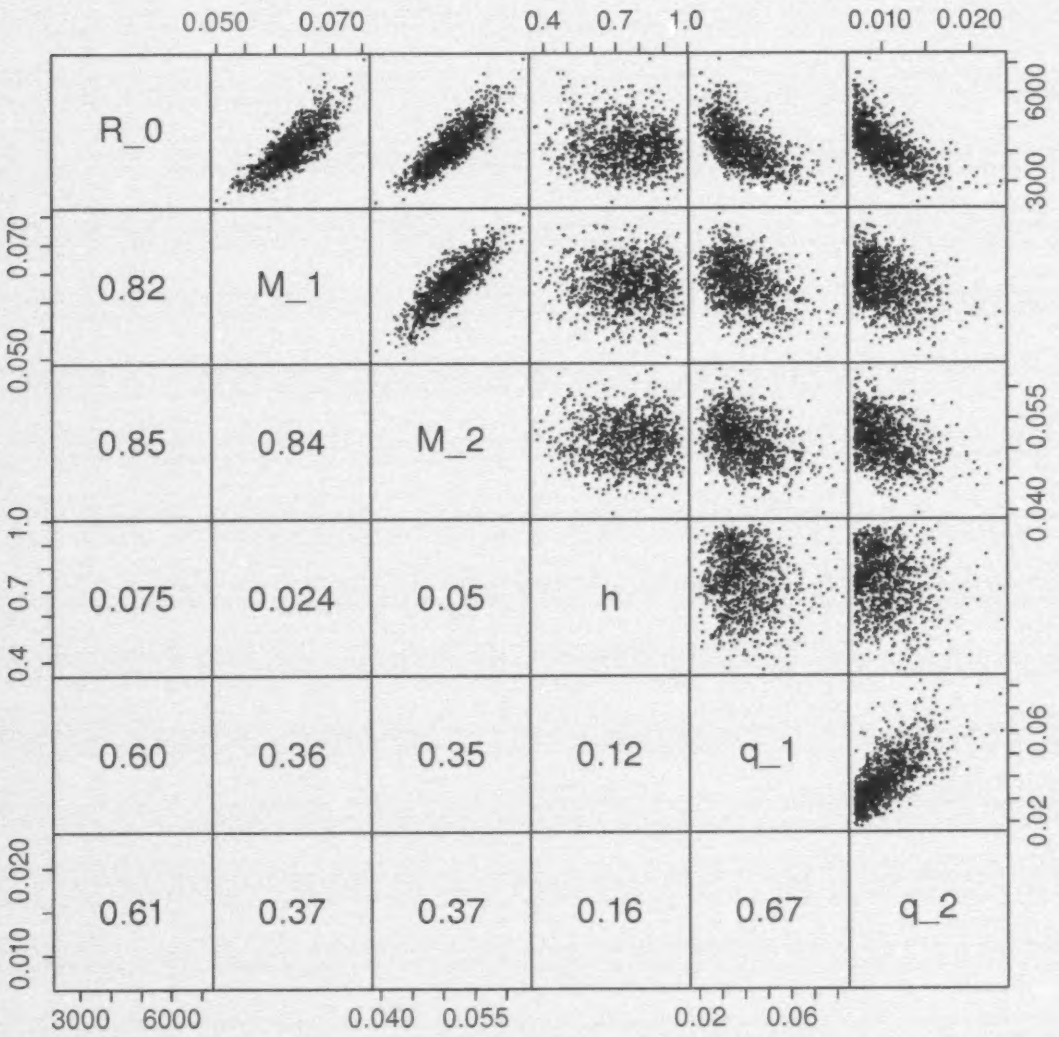

Figure E.26. Pairs plot of 1,000 MCMC samples for 1st six parameters. Numbers are the absolute values of the correlation coefficients.

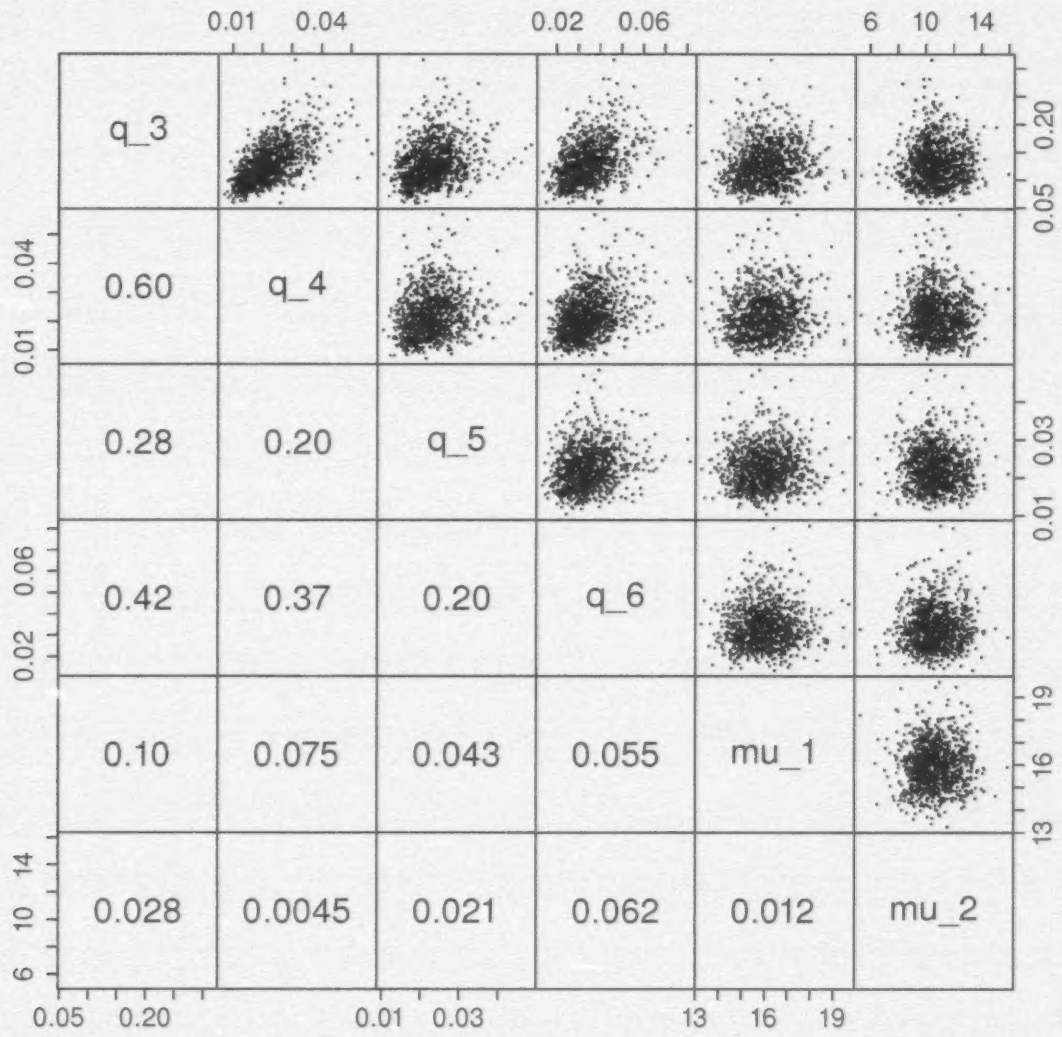

Figure E.27. Pairs plot of 1,000 MCMC samples for 2nd six parameters. Numbers are the absolute values of the correlation coefficients.

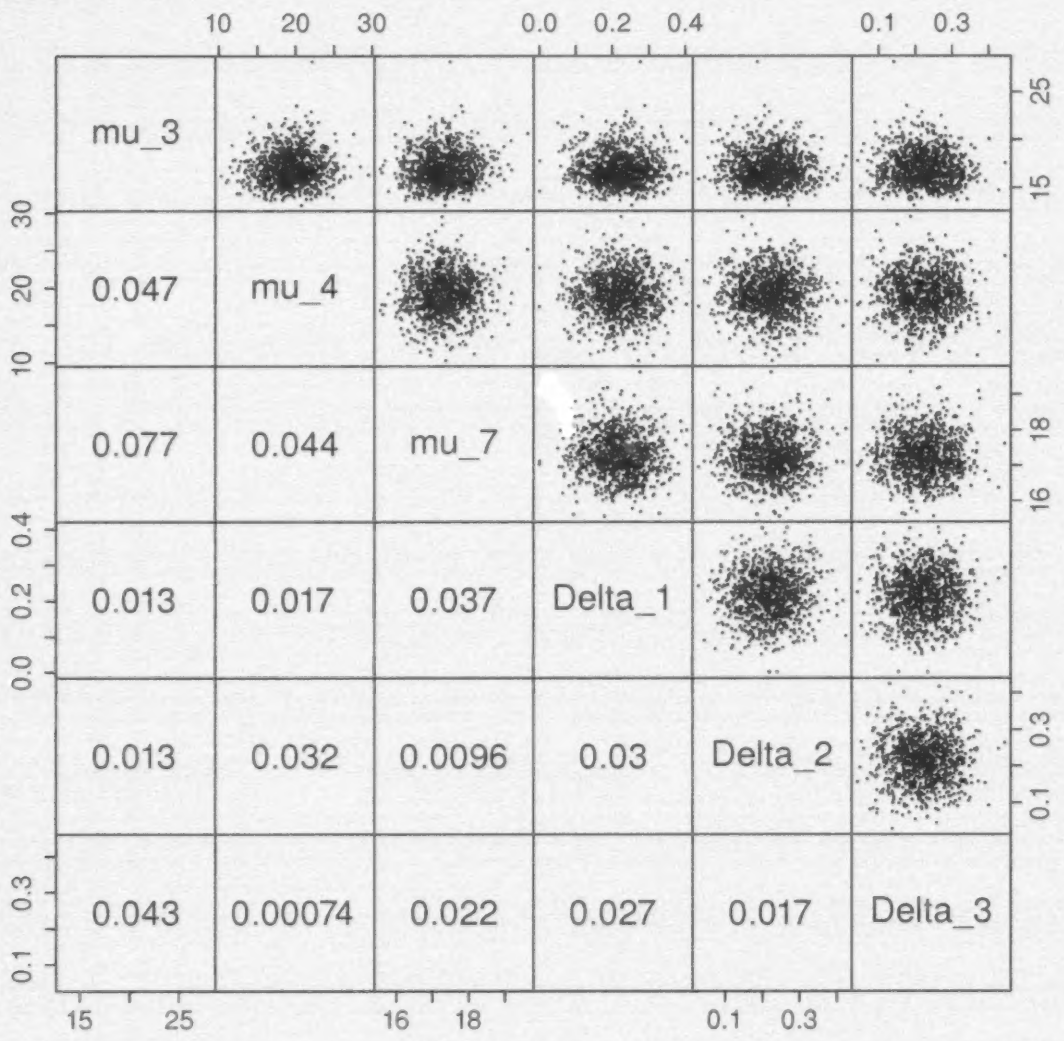

Figure E.28. Pairs plot of 1,000 MCMC samples for 3rd six parameters. Numbers are the absolute values of the correlation coefficients.

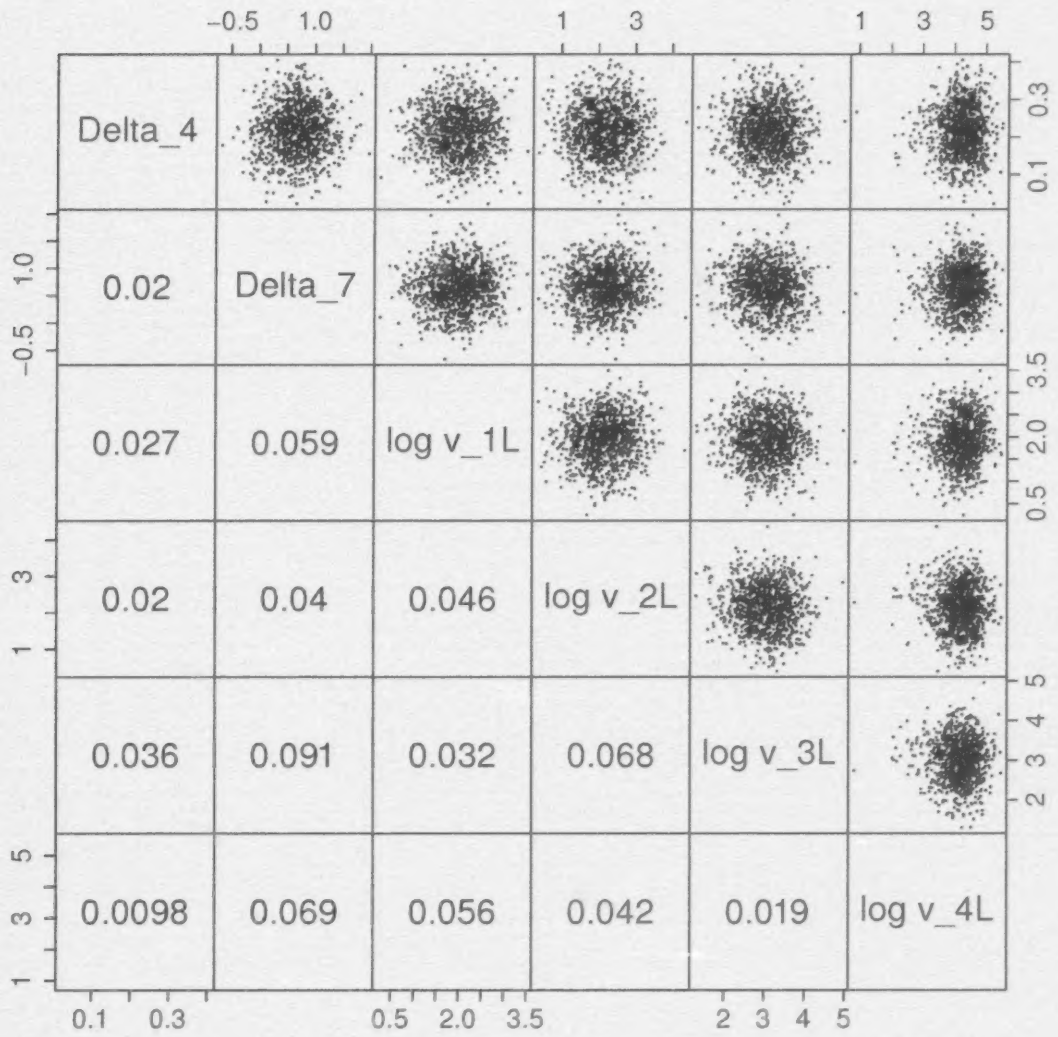

Figure E.29. Pairs plot of 1,000 MCMC samples for 4th six parameters. Numbers are the absolute values of the correlation coefficients.

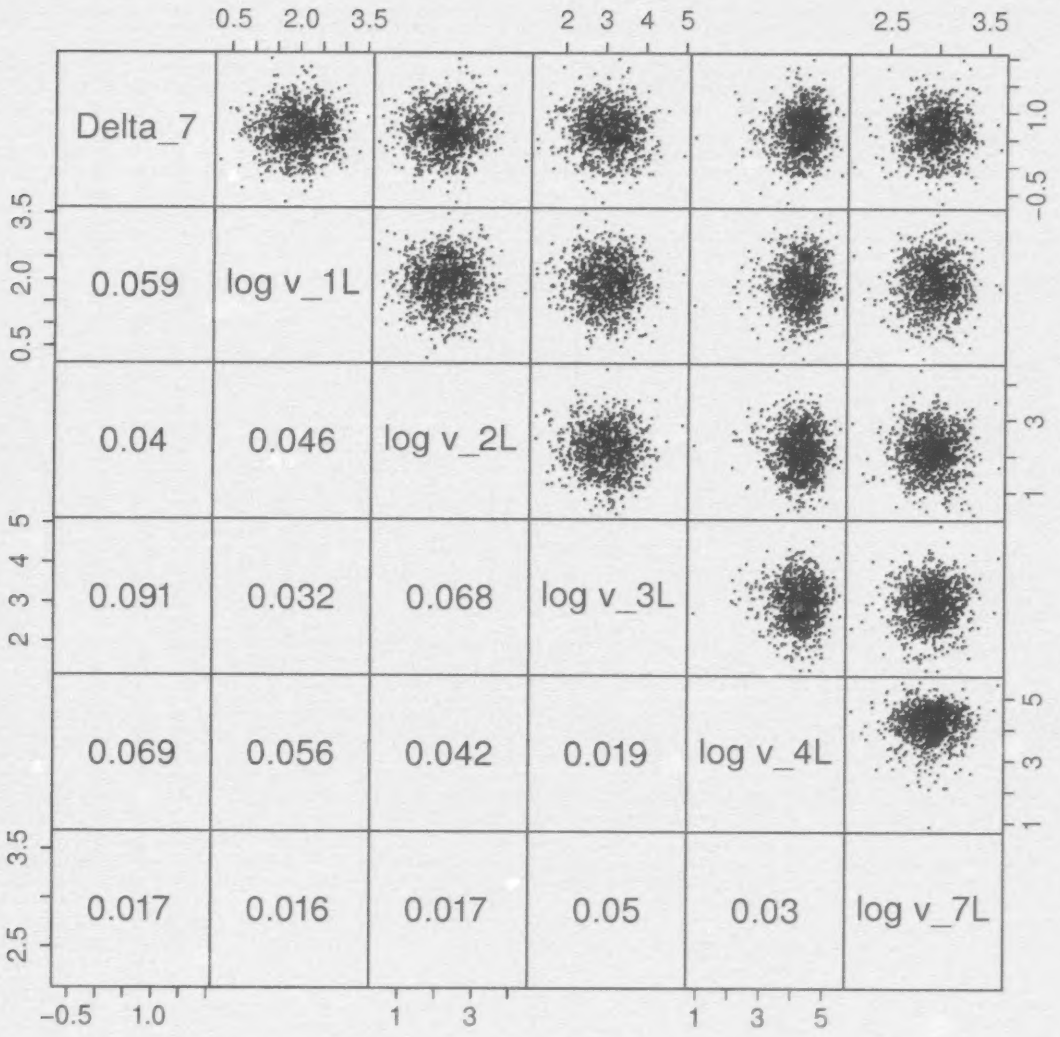

Figure E.30. Pairs plot of 1,000 MCMC samples for 5th six parameters. Numbers are the absolute values of the correlation coefficients.

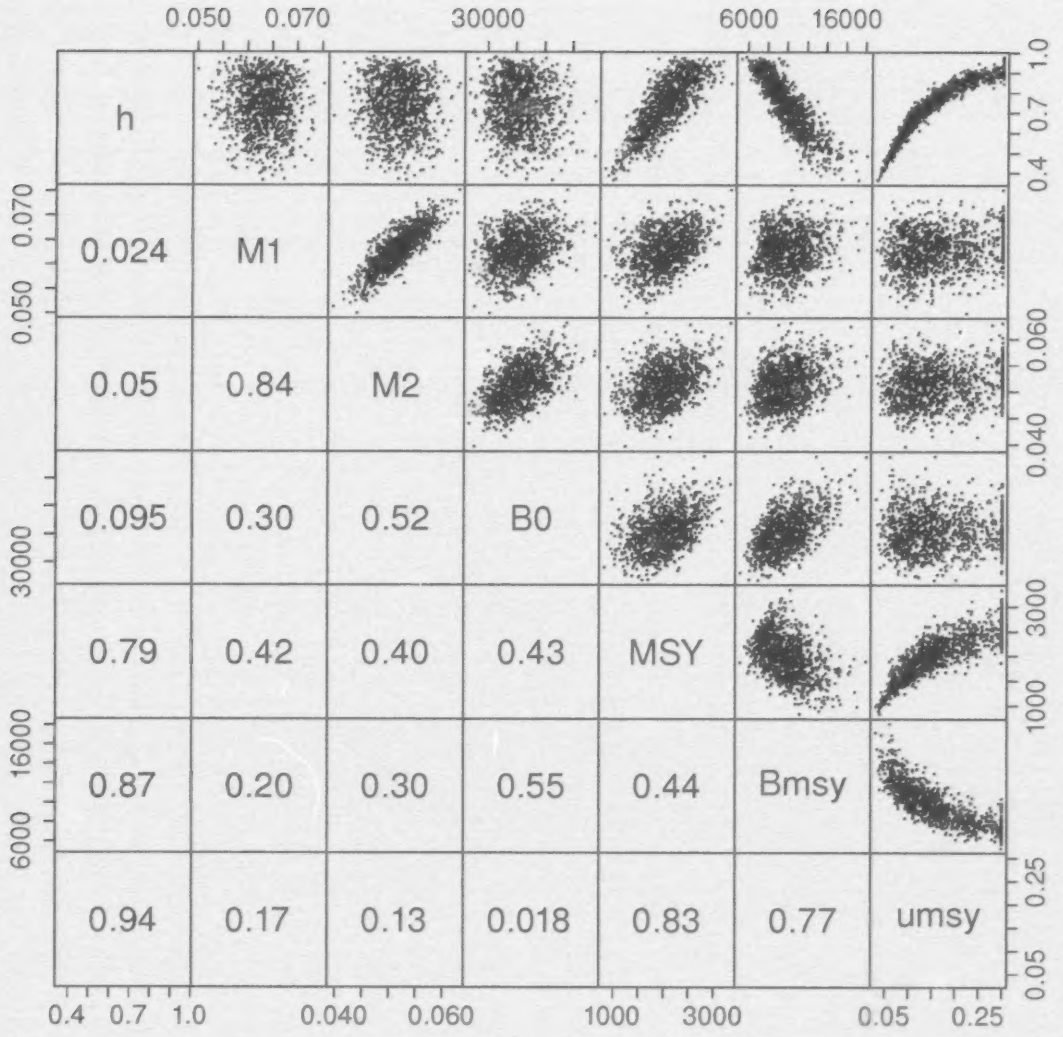

Figure E.31. Pairs plot of 1,000 MCMC samples comparing steepness h to various reference parameters. Numbers are the absolute values of the correlation coefficients.

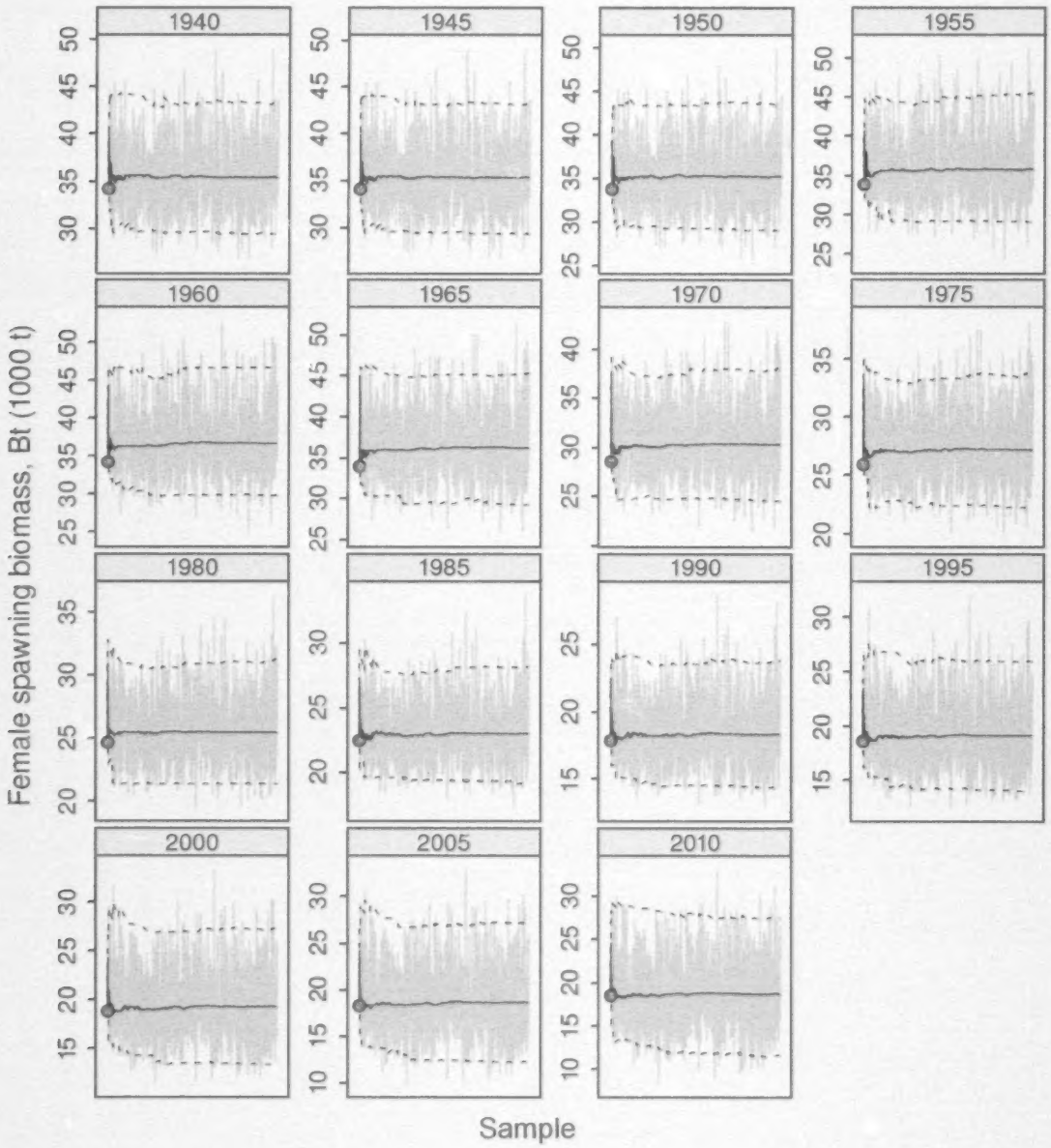

Figure E.32. MCMC traces for female spawning biomass estimates at five-year intervals. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual values). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. ed circles are the MPD estimates.

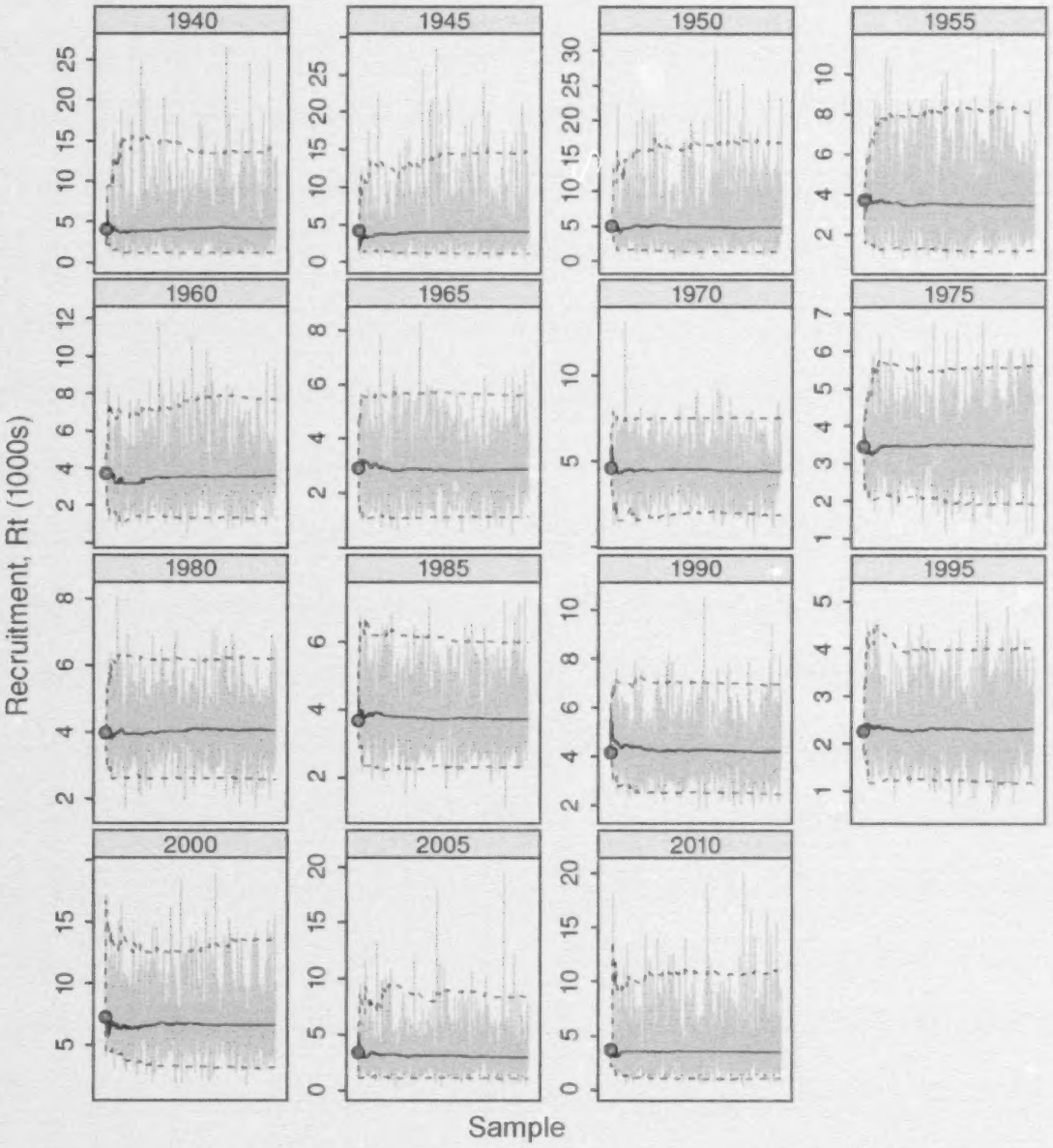

Figure E.33. MCMC traces for recruitment estimates at five-year intervals. Note that vertical scales are different for each plot (to show convergence of the MCMC chain, rather than absolute differences in annual recruitment). Grey lines show the 1,000 samples for each parameter, solid lines show the cumulative median (up to that sample), and dashed lines show the cumulative 2.5 and 97.5 quantiles. Red circles are the MPD estimates.

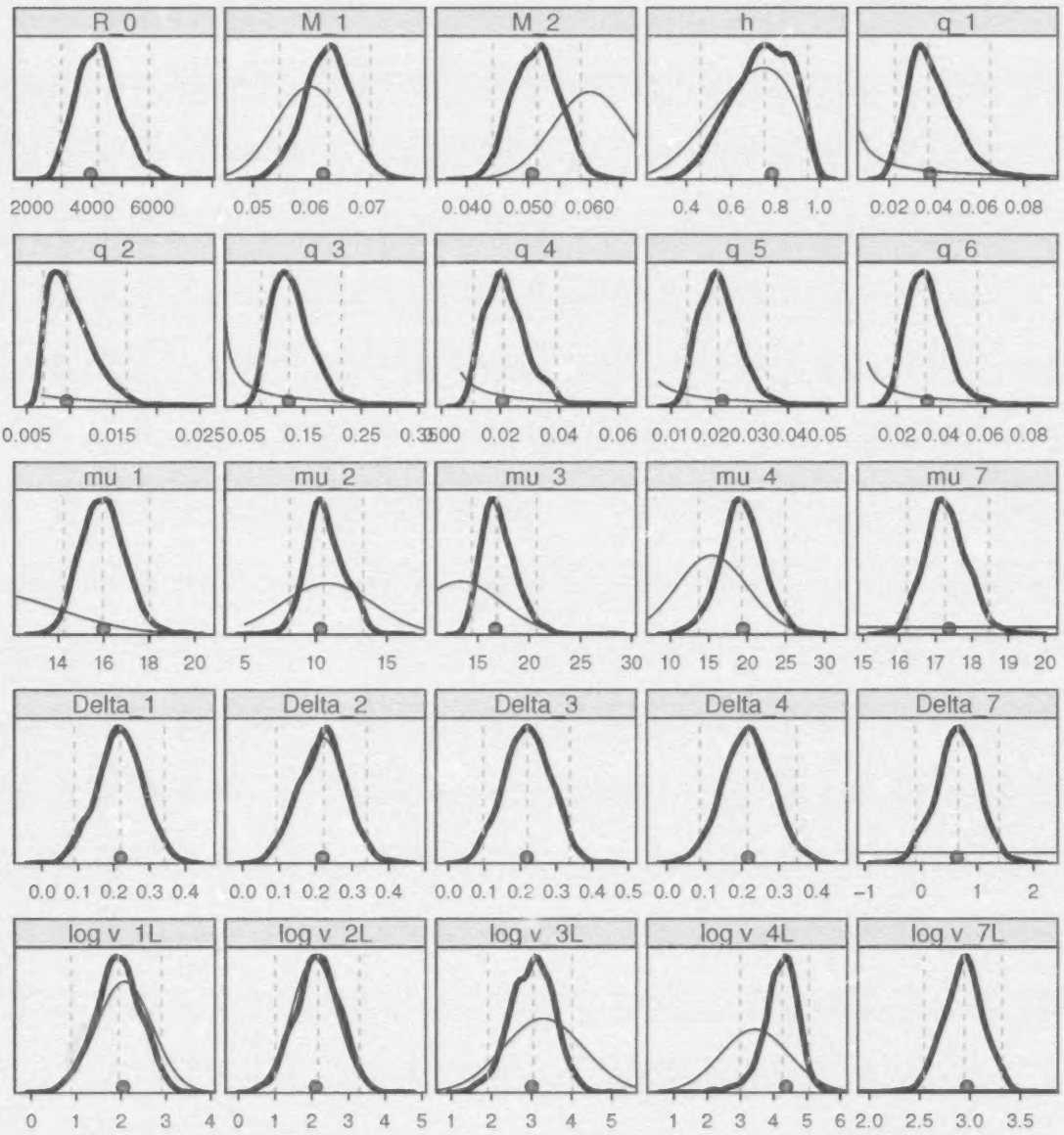

Figure E.34. Marginal posterior densities (thick black curves) and prior density functions (thin blue curves) for the estimated parameters. Vertical lines represent the 2.5, 50 and 97.5 percentiles, and red filled circles are the MPD estimates. For R_0 the prior is a uniform distribution on the range [1, 1e+05]. The priors for q_g are uniform on a log-scale, and so the probability density function is $1/(x(b-a))$ on a linear scale (where a and b are the bounds on the log scale).

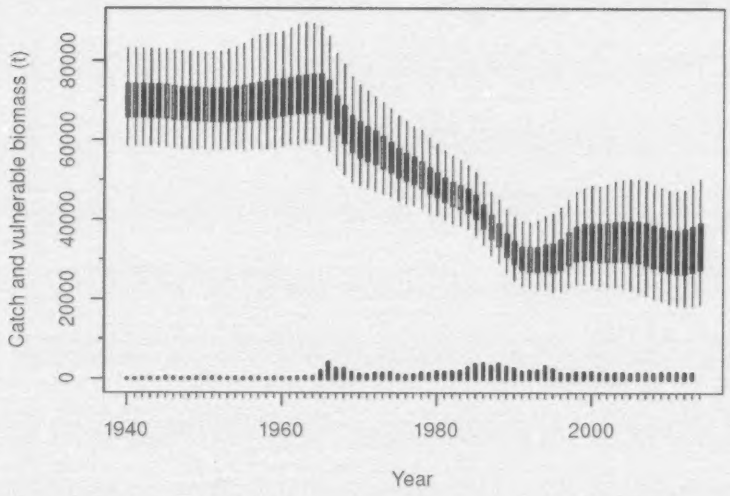

Figure E.35. Estimated vulnerable biomass (boxplots) and commercial catch (vertical bars), in tonnes, over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Catch is shown to compare its magnitude to the estimated vulnerable biomass.

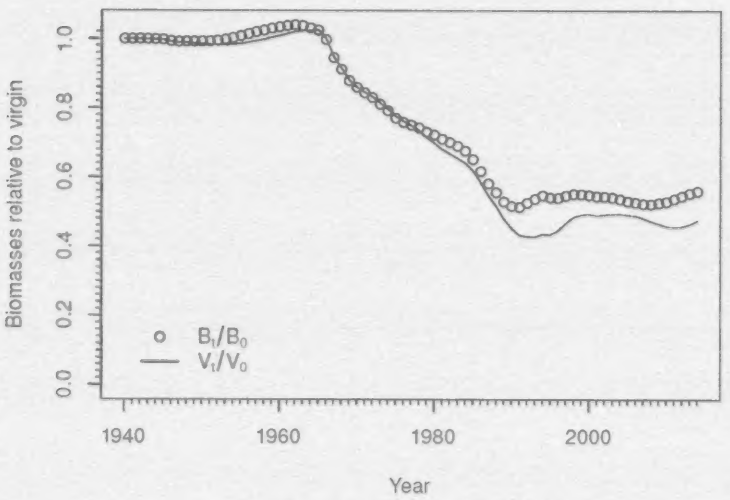

Figure E.36. Changes in B_t/B_0 and V_t/V_0 (spawning and vulnerable biomass relative to unfished equilibrium levels) over time, shown as the medians of the MCMC posteriors.

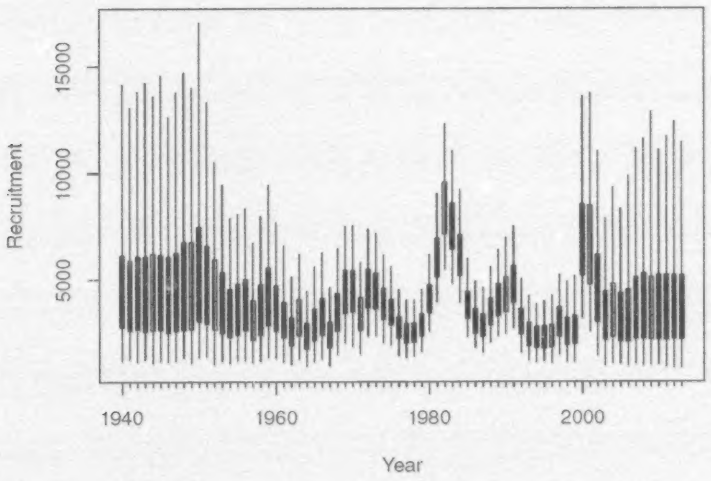

Figure E.37. Marginal posterior distribution of recruitment in 1,000s of age-1 fish plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. Note that the first year for which there are age data is 1979, and the plus-age class is 32, such that there are no direct data concerning age-1 fish before 1948. Also, the final few years have no direct age-data from which to estimate recruitment, because fish are not fully selected until age 17.3 by the commercial vessels or age 15.6 by surveys (mean of the MCMC median ages at full selectivity for commercial catch, μ_7, and survey $\mu_{1,2,3,4}$, respectively).

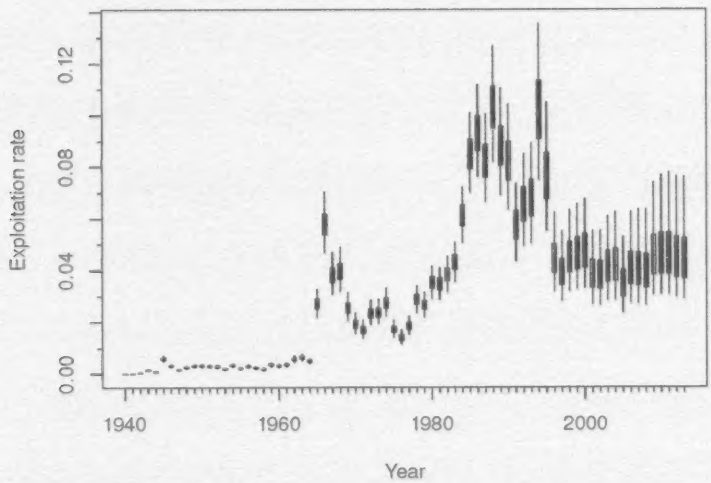

Figure E.38. Marginal posterior distribution of exploitation rate plotted over time. Boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results.

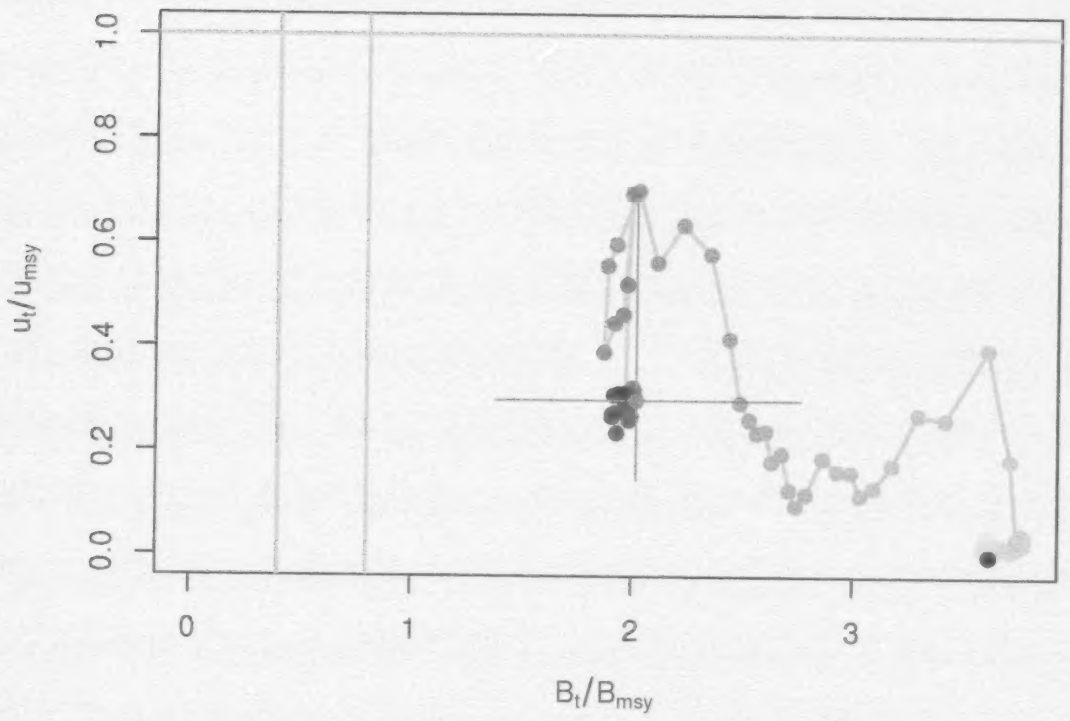

Figure E.39. Phase plot through time of the medians of the ratios B_t/B_{MSY} (the spawning biomass in year t relative to B_{MSY}) and u_t/u_{MSY} (the exploitation rate in year t relative to u_{MSY}). Blue filled circle is the starting year (1940). Years then proceed from light grey through to dark grey with the final year (2013) as a filled red circle, and the red lines represent the 10% and 90% percentiles of the posterior distributions for the final year. Vertical grey lines indicate the Precautionary Approach provisional limit and upper stock reference points (0.4, 0.8 Bmsy), and horizontal grey line indicates u at MSY.

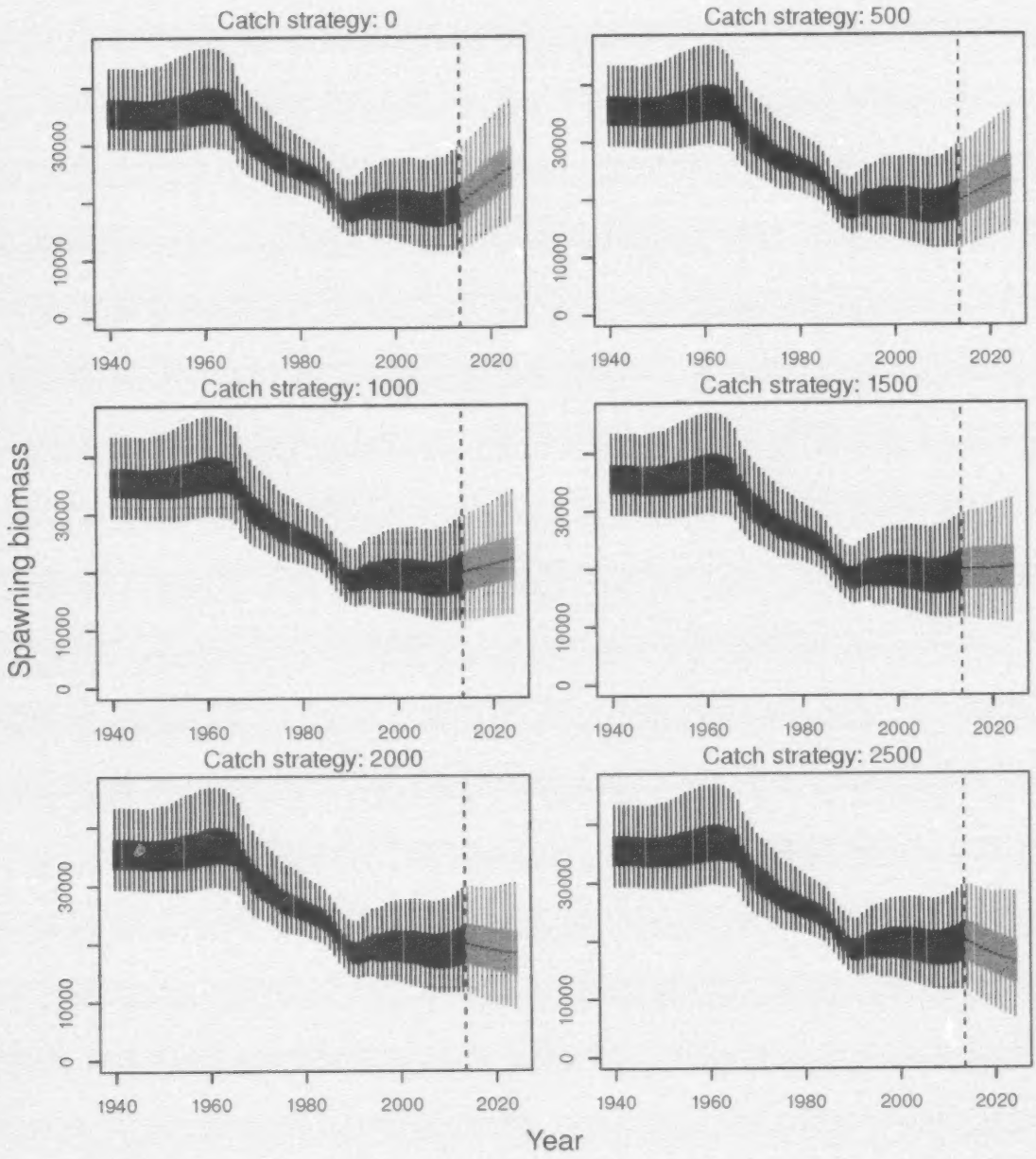

Figure E.40. Projected biomass (t) under different constant catch strategies (t); boxplots show the 2.5, 25, 50, 75 and 97.5 percentiles from the MCMC results. For each of the 1,000 samples from the MCMC posterior, the model was run forward in time (red, with medians in black) with a constant catch, and recruitment was simulated from the stock-recruitment function with lognormal error (see Appendix D). For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

Table E.1. Negative log-likelihoods and objective function from the MPD results for the two models. Parameters and likelihood symbols are defined in Appendix F. For indices ($\hat{I}_{tg}$) and proportions-at-age ($\hat{p}_{atgs}$), subscripts $g = 1...6$ refer to the trawl surveys and subscript $g = 7+$ refers to the commercial fishery.

Description	Negative log likelihood	Value
Survey 1	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t1}\right\}\right)$	-3.49
Survey 2	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t2}\right\}\right)$	-3.35
Survey 3	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t3}\right\}\right)$	-0.94
Survey 4	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t4}\right\}\right)$	0.57
Survey 5	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t5}\right\}\right)$	1.58
Survey 6	$\log \mathrm{L}_3\left(\mathbf{\Theta}\middle\vert \left\{\hat{I}_{t6}\right\}\right)$	3.92
CAs 1	$\log \mathrm{L}_2\left(\mathbf{\Theta}\middle\vert \{\hat{p}_{at1s}\}\right)$	-282.71
CAs 2	$\log \mathrm{L}_2\left(\mathbf{\Theta}\middle\vert \{\hat{p}_{at2s}\}\right)$	-286.03
CAs 3	$\log \mathrm{L}_2\left(\mathbf{\Theta}\middle\vert \{\hat{p}_{at3s}\}\right)$	-415.58
CAs 4	$\log \mathrm{L}_2\left(\mathbf{\Theta}\middle\vert \{\hat{p}_{at4s}\}\right)$	-285.88
CAc 1	$\log \mathrm{L}_2\left(\mathbf{\Theta}\middle\vert \{\hat{p}_{at7s}\}\right)$	-3547.73
Prior	$\log \mathrm{L}_1\left(\mathbf{\Theta}\middle\vert \{\epsilon_t\}\right) - \log\left(\pi(\mathbf{\Theta})\right)$	15.09
	Objective function $f(\mathbf{\Theta})$	-4804.55

Table E.2. The 5th, 50th, and 95th percentiles for model parameters derived via MCMC estimation (defined in Appendix D).

	5%	50%	95%
R_0	3,153	4,194	5,492
M_1	0.05607	0.06324	0.06925
M_2	0.04563	0.05142	0.05743
h	0.5076	0.7499	0.9309
q_1	0.02467	0.03747	0.06008
q_2	0.007014	0.009638	0.01535
q_3	0.08021	0.1243	0.1944
q_4	0.01189	0.02107	0.03613
q_5	0.01513	0.02200	0.03185
q_6	0.02114	0.03290	0.05135
μ_1	14.49	15.94	17.61
μ_2	8.607	10.54	12.99
μ_3	14.66	16.83	20.10
μ_4	14.57	19.27	23.90
μ_7	16.37	17.26	18.26
Δ_1	0.1086	0.2186	0.3237
Δ_2	0.1107	0.2219	0.3232
Δ_3	0.1130	0.2187	0.3244
Δ_4	0.1071	0.2161	0.3242
Δ_7	-0.002717	0.6623	1.259
$\log v_{1L}$	1.079	1.950	2.740
$\log v_{2L}$	1.171	2.178	3.111
$\log v_{3L}$	2.148	3.048	3.858
$\log v_{4L}$	3.276	4.263	4.949
$\log v_{7L}$	2.605	2.945	3.269

Table E.3. The 5th, 50th and 95th percentiles of MCMC-derived quantities from the 1,000 samples of the MCMC posterior. Definitions are: B_0 – unfished equilibrium spawning biomass (mature females), V_0 – unfished equilibrium vulnerable biomass (males and females), B_{2014} – spawning biomass at the start of 2014, V_{2014} – vulnerable biomass in the middle of 2014, u_{2013} – exploitation rate (ratio of total catch to vulnerable biomass) in the middle of 2013, $u_{\max}$ – maximum exploitation rate (calculated for each sample as the maximum exploitation rate from 1940-2013), B_{MSY} – equilibrium spawning biomass at MSY (maximum sustainable yield), u_{MSY} – equilibrium exploitation rate at MSY, V_{MSY} – equilibrium vulnerable biomass at MSY. All biomass values (and MSY) are in tonnes. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

Value	Percentile		
	5%	50%	95%
	From model output		
B_0	30,135	35,387	41,926
V_0	60,849	69,565	81,206
B_{2014}	12,669	19,803	28,070
V_{2014}	20,759	32,832	47,679
B_{2014}/B_0	0.405	0.559	0.698
V_{2014}/V_0	0.334	0.474	0.601
u_{2013}	0.03	0.044	0.068
	MSY-based quantities		
B_{MSY}	7,089	9,718	13,717
$0.4B_{\mathrm{MSY}}$	2,836	3,887	5,487
$0.8B_{\mathrm{MSY}}$	5,671	7,774	10,974
$B_{2014}/B_{\mathrm{MSY}}$	1.223	2.035	2.997
MSY	1,299	1,998	2,688
u_{MSY}	0.064	0.145	0.3
$u_{2013}/u_{\mathrm{MSY}}$	0.127	0.298	0.883

Table E.4. Decision table concerning the limit reference point $0.4B_{\mathrm{MSY}}$ for 1-10 year projections for a range of constant catch strategies (in tonnes). Values are $P(B_t > 0.4B_{\mathrm{MSY}})$, i.e. the probability of the spawning biomass (mature females) at the start of year t being greater than the limit reference point. The probabilities are the proportion (to two decimal places) of the 1000 MCMC samples for which $B_t > 0.4B_{\mathrm{MSY}}$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
2750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
3000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99

Table E.5. Decision table concerning the upper reference point $0.8B_{\mathrm{MSY}}$ for 1-10 year projections, such that values are $P(B_t > 0.8B_{\mathrm{MSY}})$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99
1750	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99
2000	1.00	1.00	1.00	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
2250	1.00	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98
2500	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.96
2750	1.00	1.00	0.99	0.99	0.98	0.98	0.97	0.97	0.96	0.94	0.93
3000	1.00	1.00	0.99	0.99	0.98	0.97	0.96	0.95	0.93	0.92	0.89

Table E.6. Decision table concerning the reference point B_{MSY} for 1-10 year projections, such that values are $P(B_t > B_{MSY})$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
250	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
500	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00
750	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1000	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1250	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.98
1500	0.99	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
1750	0.99	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
2000	0.99	0.99	0.98	0.98	0.98	0.97	0.97	0.97	0.96	0.96	0.95
2250	0.99	0.99	0.98	0.98	0.97	0.96	0.96	0.95	0.94	0.93	0.92
2500	0.99	0.98	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.90	0.89
2750	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.91	0.88	0.87	0.85
3000	0.99	0.98	0.97	0.96	0.94	0.92	0.90	0.87	0.85	0.83	0.80

Table E.7. Decision table for comparing the projected biomass to the current biomass, given by probabilities $P(B_t > B_{2014})$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
250	0.00	1.00	1.00	0.99	0.99	1.00	0.99	1.00	1.00	1.00	1.00
500	0.00	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
750	0.00	0.98	0.96	0.96	0.95	0.95	0.95	0.95	0.95	0.95	0.95
1000	0.00	0.92	0.89	0.88	0.88	0.87	0.86	0.86	0.86	0.86	0.86
1250	0.00	0.81	0.77	0.74	0.72	0.71	0.70	0.71	0.71	0.71	0.72
1500	0.00	0.64	0.56	0.54	0.53	0.52	0.53	0.53	0.53	0.54	0.54
1750	0.00	0.43	0.37	0.35	0.35	0.36	0.37	0.37	0.38	0.38	0.37
2000	0.00	0.25	0.21	0.20	0.20	0.22	0.23	0.23	0.24	0.23	0.22
2250	0.00	0.15	0.13	0.12	0.12	0.12	0.13	0.14	0.14	0.14	0.13
2500	0.00	0.09	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08
2750	0.00	0.04	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05
3000	0.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table E.8. Decision table for comparing the projected exploitation rate to that at MSY, such that values are $P(u_t > u_{\mathrm{MSY}})$, i.e. the probability of the exploitation rate in the middle of year t being greater than that at MSY. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1000	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
1250	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
1500	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1750	0.06	0.06	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.08	0.08
2000	0.09	0.09	0.09	0.10	0.10	0.11	0.12	0.12	0.13	0.13	0.14
2250	0.12	0.12	0.12	0.14	0.15	0.16	0.17	0.19	0.20	0.21	0.21
2500	0.16	0.17	0.18	0.19	0.21	0.22	0.24	0.25	0.26	0.27	0.28
2750	0.20	0.22	0.23	0.25	0.27	0.28	0.30	0.31	0.33	0.35	0.36
3000	0.25	0.26	0.28	0.29	0.31	0.33	0.36	0.38	0.40	0.42	0.44

Table E.9. Decision table for the alternative limit reference point $0.2B_0$ for 1-10 year projections, such that values are $P(B_t > 0.2B_0)$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1750	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99
2500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.98
2750	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99	0.98	0.97
3000	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.98	0.97	0.97	0.95

Table E.10. Decision table for the alternative upper reference point $0.4B_0$ for 1-10 year projections, such that values are $P(B_t > 0.4B_0)$. For reference, the average catch over the last 5 years (2009-2013) is 1431 t.

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
0	0.96	0.97	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00	1.00
250	0.96	0.97	0.98	0.98	0.99	0.99	0.99	1.00	1.00	1.00	1.00
500	0.96	0.97	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99
750	0.96	0.97	0.97	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99
1000	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98
1250	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.97	0.97	0.97
1500	0.96	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.94	0.94	0.94
1750	0.96	0.95	0.95	0.94	0.93	0.93	0.92	0.92	0.91	0.91	0.90
2000	0.96	0.95	0.94	0.93	0.91	0.90	0.89	0.88	0.86	0.85	0.84
2250	0.96	0.94	0.92	0.90	0.88	0.86	0.84	0.82	0.81	0.79	0.77
2500	0.96	0.94	0.91	0.88	0.86	0.83	0.80	0.78	0.75	0.72	0.69
2750	0.96	0.93	0.89	0.86	0.83	0.79	0.77	0.72	0.69	0.66	0.62
3000	0.96	0.93	0.88	0.85	0.80	0.76	0.71	0.66	0.62	0.57	0.53

APPENDIX F. SENSITIVITY ANALYSES

Sensitivity analyses were used to investigate how choices made during stock assessment model formulation affected results. These analyses focused on the maturity ogive, the prior distributions specified for the selectivities, and whether natural mortality (M) was estimated or fixed. Two additional MPD sensitivity runs involving survey indices were also performed: one testing the effect of alternative added process error to the survey abundance series and the other including survey indices that were omitted from the base run. A summary of the base case and the sensitivity models runs completed is shown in Table F.1. The results from these sensitivity runs are very similar to each other and to the base case model. All cases estimate depletion levels well above the Upper Stock Reference of $0.8B_{MSY}$ and return an estimated current stock status (B_{2014}/B_0) greater than $0.5B_0$. We conclude that the current base case is acceptable and that this suite of sensitivity runs does not contradict the conclusions drawn from the base case run.

Table F.1. Model runs conducted for sensitivity analyses. In the third column, if the sensitivity case was an MCMC run, n = the total length of the MCMC chain, k = the thinning interval used, and s = the number of samples.

Run ID	Description	Chain Length, Thinning Interval, No. of Samples	Notes on Model Fit
Base	Estimated M (prior mean=0.06; SD=0.006); estimated h (mean=0.674;CV=10%); six surveys (WCHG Synoptic, HS Synoptic, QC Sound Synoptic, WCVI Synoptic, Historic GB Reed, US Triennial), no CPUE series; four synoptic survey selectivities estimated using informed priors, based on associated POP assessment results and a 30% CV; commercial selectivity parameters estimated with uniform prior; two selectivities (US Triennial, Historic GB Reed) fixed using POP median values; add CV process error= c(0.2, 0.2, 0.35, 0.4, 0.4, 0.35); female maturity ogive using Apr-Jul and mature = stage 3+.	MCMC n = 10,000,000 k = 10,000 s = 1,000	- Model fits consistent with data - Acceptable MCMC convergence
S1	Same as the base, except fixed Female and Male M = 0.6.	MCMC n = 10,000,000 k = 10,000 s = 1,000	- Model fits consistent with data - Acceptable MCMC convergence
S2	Same as base, except use steeper female maturity ogive: based on Apr-Jul samples and mature = stage 2+.	MCMC n = 10,000,000 k = 10,000 s = 1,000	- Model fits consistent with data - Acceptable MCMC convergence
S3	Same as base, except estimate synoptic survey selectivities with uniform priors instead of informed priors (use same starting values as for base).	MCMC n = 10,000,000 k = 10,000 s = 1,000	- Model fits consistent with data - Acceptable MCMC convergence
S4	Same as base, except add in the 1994 (Ocean Selector) and1995 (Frosti + Ocean Selector) index data points for the Goose Island Gully (GIG) Historic survey.	MPD only	- Model fits consistent with data
S5	Same as base, except add CV process error = c(0.2, 0.2, 0.2, 0.2, 0.2, 0.2).	MPD only	- Model fits consistent with data

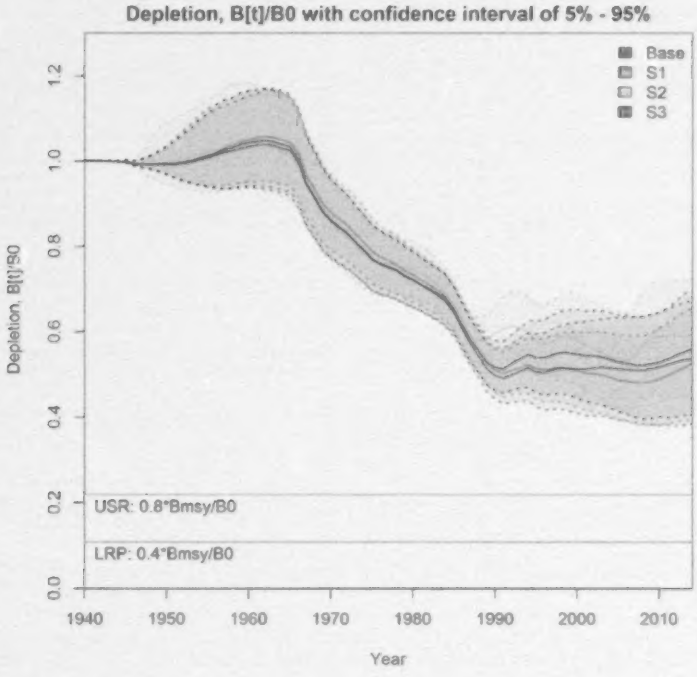

Figure F.1. Stock status (B_t/B_0) calculated from model estimates of B_{2014} and B_0, for MCMC sensitivity analysis model runs. Descriptions of each model run are given in Table F.1. Limit reference and upper stock reference are posterior median estimates of $0.4B_{MSY}/B_0$ and $0.8B_{MSY}/B_0$ respectively.

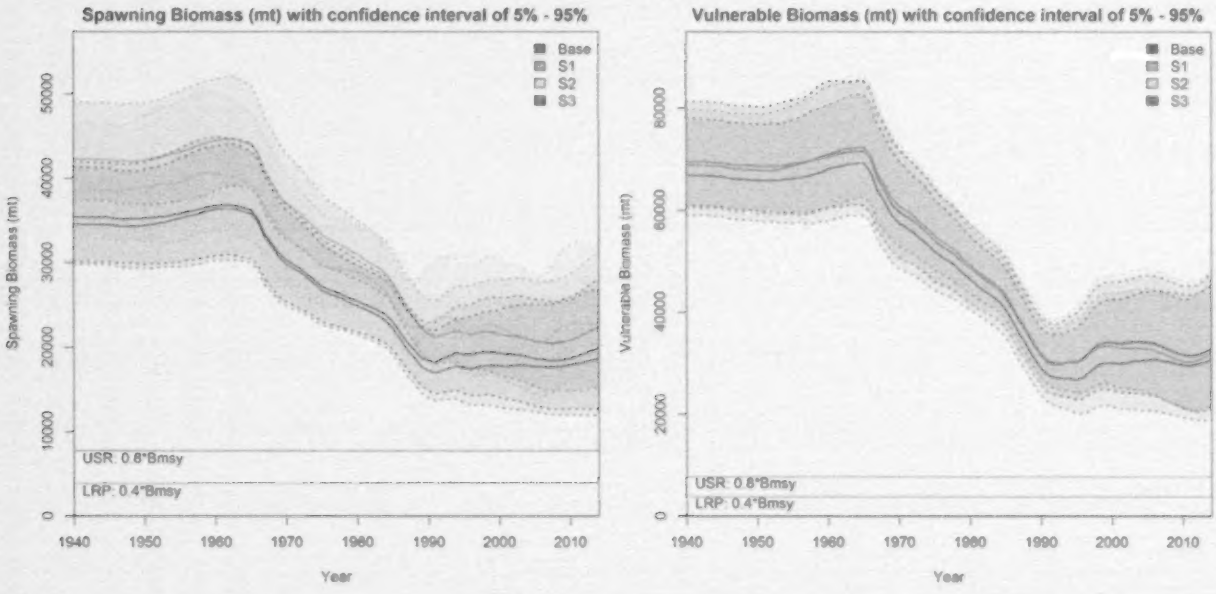

Figure F.2. Model estimates of spawning and vulnerable biomass, for MCMC sensitivity analysis model runs. Descriptions of each model run are given in Table F.1. Note that the USR and LRP values are the posterior median estimates.

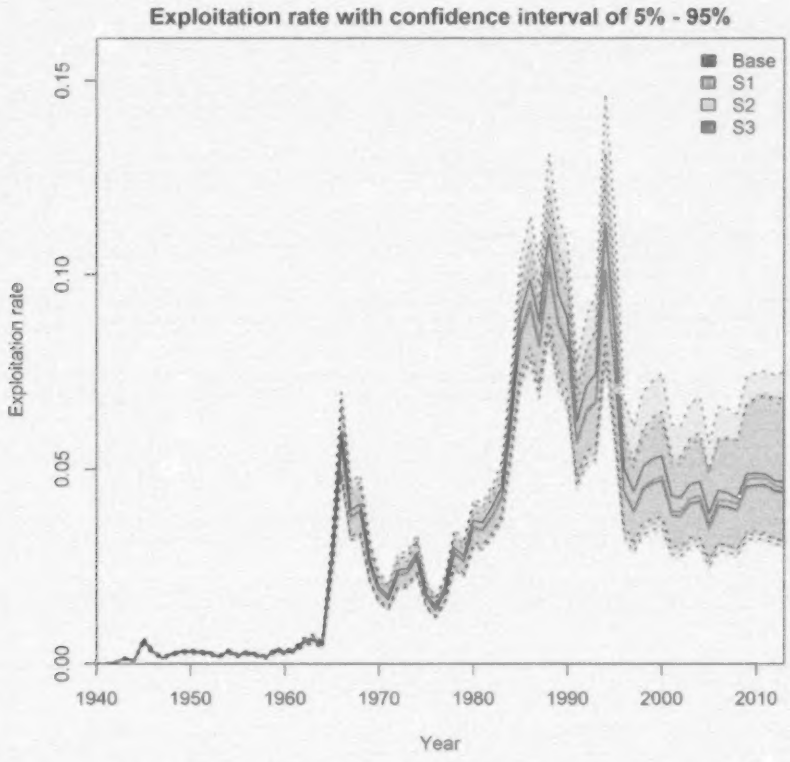

Figure F.3. Exploitation rate by year, u_t, for MCMC base and sensitivity analysis model runs. Descriptions of each model run are given in Table F.1.

Table F.2. Quantile values of MCMC parameter estimates for base and sensitivity analysis model runs. Descriptions of each model run are given in Table F.1. Parameter definitions are given in Appendix D

	Model run											
	Base			S1			S2			S3		
Parameter	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**	**5%**	**50%**	**95%**
B_0	30,134	35,387	41,926	37,351	42,297	48,980	32,893	38,615	46,470	29,837	34,530	41,289
V_0	60,848	69,565	81,205	60,434	68,856	79,659	61,043	69,632	81,473	59,029	66,851	77,872
B_t	12,669	19,802	28,070	15,217	22,336	31,193	15,385	22,853	32,224	11,950	18,501	26,815
B_{MSY}	7,089	9,717	13,717	8,149	11,336	16,063	9,153	11,576	15,375	7,082	9,630	13,523
$0.4B_0$	21,435	25,003	29,758	27,444	30,305	34,326	24,064	28,015	33,623	21,027	24,372	29,125
$0.2B_0$	13,008	17,897	22,893	15,345	20,549	25,501	14,348	20,541	27,250	12,306	16,778	22,012
B_{2014}/B_0	0.4047	0.5589	0.6979	0.3962	0.5256	0.6578	0.4458	0.5928	0.7245	0.3838	0.5362	0.6732
u_t	0.0303	0.0440	0.0682	0.0315	0.0450	0.0663	0.0300	0.0435	0.0683	0.0317	0.0466	0.0750
u_{2013}/u_{MSY}	0.0057	0.1722	0.8365	0.0061	0.1838	0.8900	0.0050	0.1406	0.6978	0.0060	0.1856	0.9415
B_{2014}/B_{MSY}	1.223	2.035	2.997	1.191	1.988	2.992	1.274	2.008	2.609	1.121	1.920	2.902

F.1. (S1) EFFECT OF FIXING NATURAL MORTALITY FOR BOTH SEXES

Fixing M for both sexes reduced the median estimate of stock status at the beginning of 2014 relative to that of the base case from 0.56 to 0.53, with the median line from this sensitivity run lying below that of the base run from 1990 onward (Figure F.*1*). This decrease is due in part to the increased estimate of B_0 when compared to the base case (Figure F.*2* panel 1, Table F.*2*). It is also likely that the average productivity for this sensitivity run is slightly less than in the base case, given the lower fixed female M in this run. Figure F.34 shows that the posterior for M_1 (female natural mortality) is shifted to the right of its prior for the base case, with the prior mean being the fixed estimate used in this sensitivity run. Exploitation rate (Figure F.*3*, Table F.*2*) is almost identical to that in the base case, showing only a slight increase between 2000 – 2014. The status relative to B_{MSY} is slightly lower for this sensitivity run compared to the base case, with the median ratio of B_{2014}/B_{MSY} equal to 1.99 compared to 2.04 for the base case.

F.2. (S2) EFFECT OF USING A STEEPER FEMALE MATURITY OGIVE

Changing the maturity ogive for females to a Stage 2+ knife-edged ogive (Figure 4, main document) had the effect of causing more variation in the size of the female spawning biomass than in the other model runs (Figure F.*2*, panel 1). This effect is even more pronounced in the trajectory of the ratio B_t/B_0 (Figure F.*1*) but is lost in the equivalent comparison between vulnerable biomass (Figure F.*2*, panel 2). The increased variability effect is less in the vulnerable biomass trajectory because vulnerable biomass is mediated through the selectivity-at-age function and also includes males while the spawning biomass trajectory contains only females and will be affected by variations in year class strength as younger recruits would be included in the mature biomass component than would be in the base case (about ⅔ of the age 8 females are mature with this ogive compared to only 20% in the Stage 3+ ogive; Table C.3). The median estimate of stock status (B_{2014}/B_0) increased from 0.56 to 0.59 while the current exploitation rate (u_{2013}; Figure F.*3*) for this sensitivity run was almost identical to the base case at all points in the time series.

F.3. (S3) EFFECT OF USING UNIFORM PRIORS FOR ESTIMATED SELECTIVITIES

This sensitivity run used uniform (non-informative) priors for all estimated selectivity parameters instead of using the informative priors based on the previous POP assessments as was done in the base case. The median estimate of stock status for this run at the beginning of 2014 relative to the base case decreased from 0.56 to 0.54 and the trajectory of B_t/B_0 lies slightly below the equivalent base case trajectory. Both the spawning and vulnerable biomass levels were slightly lower in this run compared to the base case (Figure F.*2* panels 1 and 2). Consequently, the terminal (u_{2013}: mid-year 2013) exploitation rate was slightly greater for this run compared to the base case (median values: $u_{2013} = 0.047$ for S3 compared to $u_{2013} = 0.044$ for the base case), which is likely due to the slightly smaller vulnerable biomass levels which are being exploited with the same levels of catch.

F.4. (S4) EFFECT OF RESTORING THE 1994 AND 1995 OCEAN SELECTOR / FROSTI SURVEY INDICES

These two surveys were removed from the base case by decision of the Technical Working Group in August 2013. The reasoning was that the comparability of the 1994 survey with the earlier series was lost because it differed by two months from its predecessor surveys and the 1995 survey design was considerably different from that of the earlier surveys. See the "Survey Descriptions" (Section 4) in the main document for more information. This sensitivity run was not taken to the MCMC level, so comparisons were made relative to the MPD results.

The addition of these two survey indices resulted in lowest trajectory of B_t/B_0 among the six model runs (Figure F.4). The estimates of spawning biomass, vulnerable biomass, B_0, and R_0 are also the lowest among the base case and the five sensitivity runs (Figure F.5, Table F.3) . This sensitivity run also had the lowest estimate of B_{2014}/B_0 and the highest exploitation rate among all the runs (Figure F.6). However, to put these results in context, the estimate for B_{2014}/B_0 was still greater than $0.5B_0$ ($B_{2014}/B_0 = 0.53$: Table F.3) and the estimated exploitation rate was still less than the estimates of M and much less than u_{MSY}, leading to the conclusion that this sensitivity run did not contradict the overall conclusions of the assessment.

F.5. (S5) EFFECT OF FIXING PROCESS ERROR AT 0.2 FOR ALL SURVEY INDICES

For this sensitivity run, the added process error to all six survey CVs was set to 0.2, following the main recommendation of Francis (2011). The parameter estimates for this run were closest to those of the base case (Table F.3; Figure F.4) with this run having a slightly elevated estimate of B_{2014}/B_0 relative to the base case ($B_{2014}/B_0 = 0.60$ compared to the base case MPD $B_{2014}/B_0 = 0.58$; Table F.3). The differences between the remaining parameter estimates from this sensitivity run and the base case were minimal.

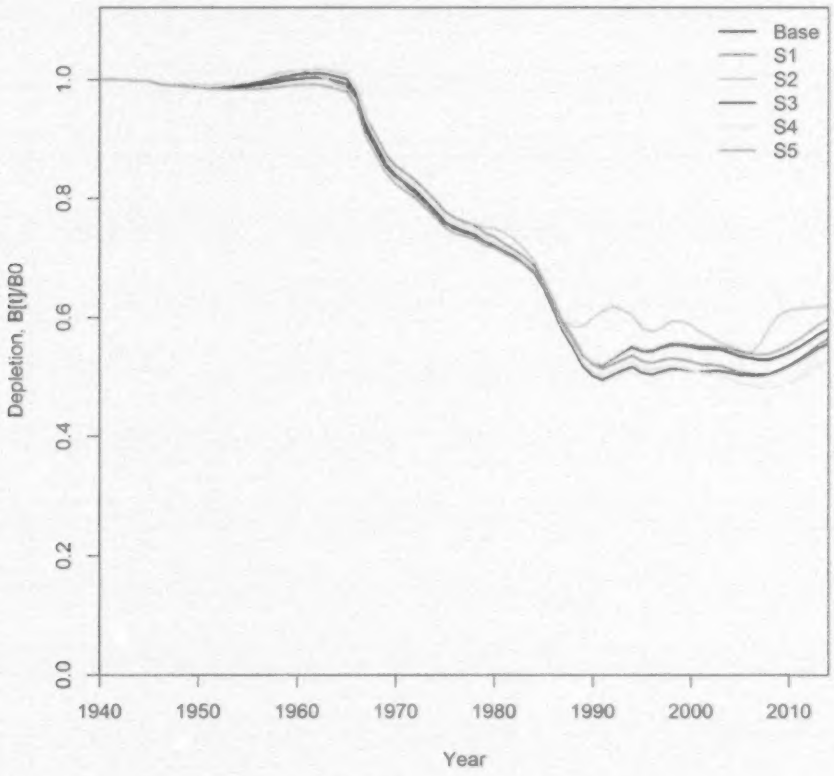

Figure F.4. Stock status, also called depletion (B_t/B_0), calculated from model estimates of B_t and B_0, for MPD sensitivity analysis model runs. Descriptions of each model run are given in Table F.1.

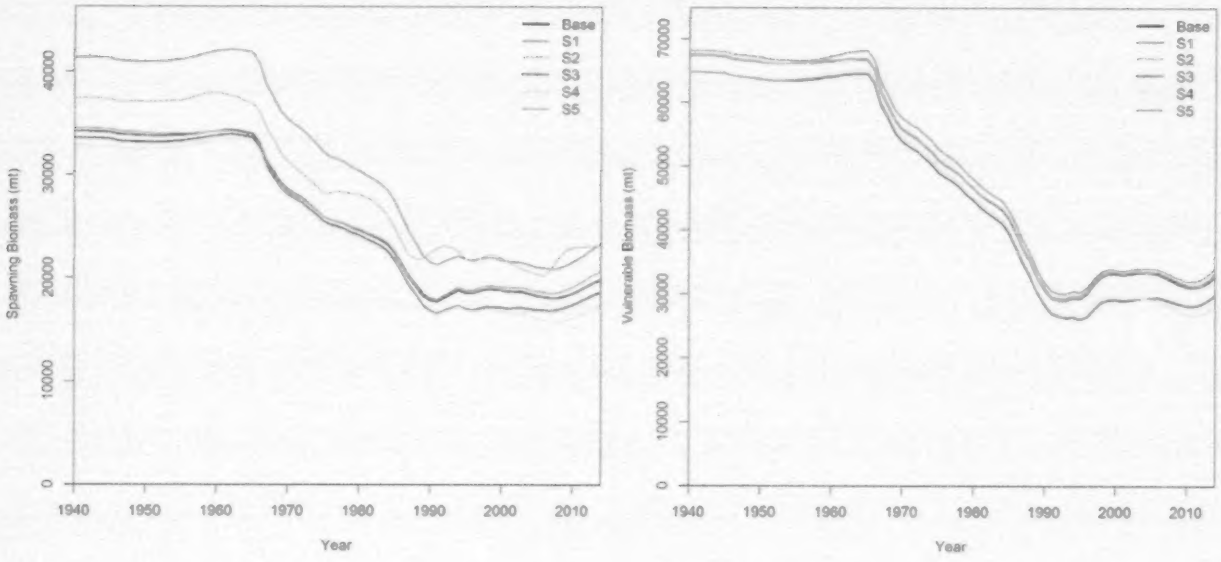

Figure F.5. Model estimates of Vulnerable biomass and Spawning Biomass, for MPD sensitivity analysis model runs. Descriptions of each model run are given in Table F.1.

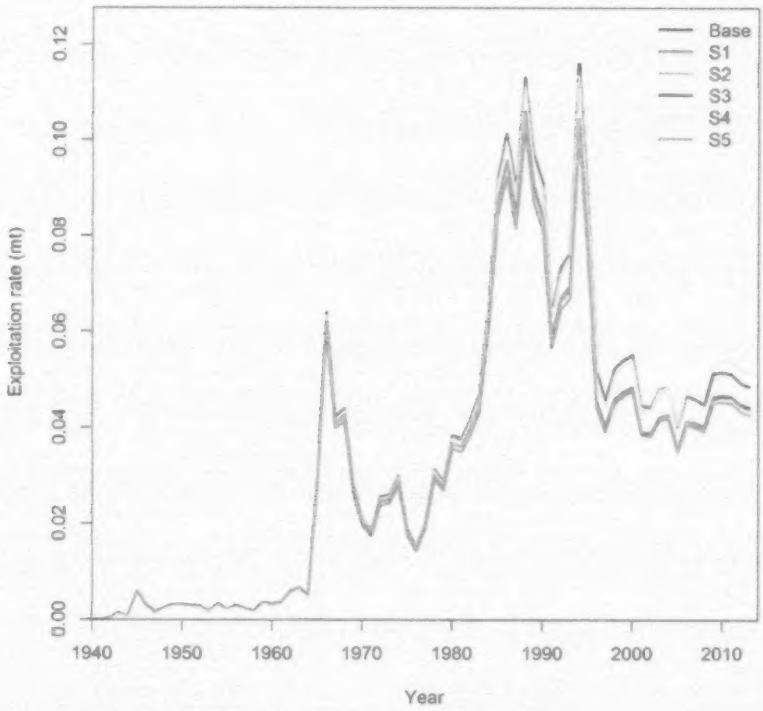

Figure F.6. Exploitation rate by year, u_t, for MPD base and sensitivity analysis model runs. Descriptions of each model run are given in Table F.1.

Table F.3. MPD parameter estimates for base and sensitivity analysis model runs. Descriptions of each model run are given in Table F.1. Parameter definitions are given in Appendix D. Values in grey were fixed.

	Model run					
Parameter	**Base**	**S1**	**S2**	**S3**	**S4**	**S5**
B_{2014}	19,836	23,356	23,187	18,639	17,350	20,524
V_{2014}	32,738	33,281	33,104	29,812	28,104	34,011
B_0	34,194	41,389	37,438	33,537	32,841	34,514
R_0	3,953	4,479	3,957	3,774	3,688	3,983
B_{2014}/B_0	0.5801	0.5643	0.6193	0.5558	0.5283	0.5976
u_{2014}	0.0442	0.0438	0.0437	0.0485	0.0515	0.0426
M_{Female}	0.0623	0.0600	0.0623	0.0614	0.0613	0.0623
h	0.7846	0.7708	0.7877	0.7827	0.7600	0.7954
q_1	0.0382	0.0381	0.0378	0.0434	0.0438	0.0373
q_2	0.0096	0.0093	0.0095	0.0106	0.0110	0.0093
q_3	0.1239	0.1238	0.1227	0.1463	0.1430	0.1102
q_4	0.0207	0.0208	0.0205	0.0282	0.0241	0.0176
q_5	0.0230	0.0220	0.0230	0.0239	0.0180	0.0217
q_6	0.0339	0.0328	0.0337	0.0368	0.0367	0.0308